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PLANT SUCCESSION STUDIES ON SUBALPINE ACID MINE SPOILS IN THE BEARTOOTH MOUNTAINS

by

Patricia Lea Howard

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Ecology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1978

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Patricia Lea Howard

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ABSTRACT

Plant Succession Studies on Subalpine Acid Mine

Spoils in the Beartooth Mountains

by

Patricia Lea Howard, Master of Science

Utah State University, 1978

Major Professor: Dr. Thadis W. Box
Department: Range Science

Large areas within alpine and subalpine tundra have been disturbed by mining during this century. The most promising method for retarding deterioration of these areas is revegetation with native species through both seeding and transplants. One natural process of revegetation which occurs on portions of many existing disturbances seems to be the establishment of a few species that expand with time to form matts of plants.

At the McLaren Mine, located at 3000 m elevation in the Beartooth Mountains, Montana, active succession is occurring and is dominated by *Carex* species. Seed viability and successional patterns studies were conducted on the mine. The objectives included: 1) determinations of seed viability on the spoils, 2) determine to what extent the *Carex* communities enhanced seedling survival, 3) to quantify the vegetation characteristics within the *Carex* communities and adjacent mine spoil, and 4) determine the effect that *Carex* communities have on microenvironmental factors. Greenhouse tests were used to determine seed viability in soil samples taken from the mine. Paired observations in field studies were used to compare vegetational and microenvironmental differences between *Carex* communities and adjacent bare areas.

Statistical analyses of the data collected showed that there was an adequate source of viable seeds of various species in the spoils to encourage natural revegetation if they could become established. Seedling mortality was reduced in *Carex* communities, apparently by decreasing soil disruption caused by frost action. *Carex* communities altered the microenvironment by reducing soil temperatures, wind speed, and radiation flux, and by providing a richer source of nitrogen and potassium than did the bare areas. *Carex* communities did not alter soil pH, phosphorus or soil water. Measurement of microenvironmental factors varied between the center and edge locations within the *Carex* communities. Species diversity and percent litter cover increased with increase in community size.

(103 pages)

INTRODUCTION

Subalpine regions cover an extensive area in North America. These high elevation ecosystems are important for their value as municipal and agricultural watersheds, as a source of minerals, as rangelands, as wildlife habitat, and as recreation areas.

Large areas within these ecosystems have been disturbed by mining during this century. Present and future demands for minerals, such as chromium, will greatly increase the extent of disturbance (Stoneberg 1976).

The environments of high elevation tundra communities are harsh and approach the upper altitudinal limits of vascular plant growth. They are characterized by long snowy winters, short growing seasons with low night temperatures, high winds and high solar radiation (Billings 1973, Löve 1970). The soils are shallow, usually poorly developed and low in nutrients necessary for plant growth (Nimlos and McConnell 1965, Retzer 1974). The vegetation is characterized primarily by perennial herbaceous plants and shrubs low in stature. Plant taxa are comprised of a mix of relatively ancient alpine flora and new flora from lower elevations adapted to cold environments through relatively rapid evolutionary changes since Pleistocene post-glaciation (Billings 1974).

Once these eocsystems are disturbed by such activities as mining, re-establishment of a protective vegetative cover is extremely slow. The re-establishment of a climax community, through the processes of succession, may take hundreds of years (Billings 1973, Zwinger and Willard 1972).

Revegetation of these areas is, at the present, the most successful long-term method of retarding deteriorationg. One of the most promising revegetation techniques in high elevation areas appears to be the useof native species, through both seeding and transplants (Brown and Johnston 1976).

Little research has been done on the rehabilitation of disturbed alpine and subalpine tundra. Most of the present techniques have been developed for lower elevation conditions where there are less severe environmental conditions and where there is a greater species diversity available than at higher elevations. Mine disturbances at high elevations greatly increases the severity of the naturally harsh environment. Johnson et al. (1975) describe the major factors limiting plant establishment and growth on alpine surface mines. Techniques for lower elevation disturbances must be greatly modified to be effective in rehabilitation of high elevation disturbances.

The alpine flora of the Beartooth Plateau is comprised of about 200 species (Johnson and Billings 1962). There are probably 200-300 species in the alpine-subalpine transition zone, but only about 10 percent of the flora appears to be active colonizers. Natural disturbance is a frequent phase of cyclic successional changes in alpine and subalpine vegetation (Churchill and Hansen 1958). Many species have characteristics that are well adapted to plant establishment in disturbed areas either as pioneer species or invader species. Some of the more important adaptive characteristics include seed germination requirements (Amen 1965, Mooney 1963), growth forms such as cushion and rosette plants, strong tap roots (Griggs 1956), and vegetative propagation through rhizomes and stolons (Holch et al. 1941). Active colonizers include both dicotyledonous and monocotyledonous plants (Johnson and Billings 1962, Langeheim 1956). On acid mine spoils, perennial grasses and sedges are the most important active colonizers (Brown et al. 1976).

Natural revegetation occurs on portions of many of the existing mine disturbances throughout the alpine and subalpine tundra. One natural process, involving only a few species, seems to be the establishment of plants in the form of a small mat that expands through time to form a ring. The original species appear to modify the microenvironmental conditions and to encourage establishment of other species within the ring. Eventually, they form a large heterogeneous mat of vegetation.

It is not known how the original plants become established. There appears to be at least three methods of establishment on the mine spoils: 1) from seed blown onto the spoils, 2) from remnants of the original vegetation mixed into the spoils, and 3) by vegetative propagules transported during disturbance. Carex appears to be the main genus involved in the establishment of these mats or rings. These mat formations will be referred to as Carex communities in this paper.

Once the Carex plant is established, it developes into a circular pattern as the original plant spreads laterally by rhizomes. These mats vary in size. The rate of development is apparently dependent on age and immediate microenvironmental conditions. At one stage of development, the dead centers seem to be invaded by a number of other species as well as re-invaded by the ring of live Carex surrounding the center. After an undetermined length of time, more species invade the continually growing Carex community, eventually developing a hetergeneous mat of vegetation, similar in species present and distribution to the adjacent undisturbed vegetation.

A better understanding of this natural process has potential for modifying and improving present revegetation techniques in some alpine and subalpine tundra regions. It is possible that natural plant successional processes may be useful for rehabilitation of disturbed lands, particularly in severe environments.

The purpose of the present study is to better understand how these Carex communities modify the microenvironment and encourage establishment of other plant species. It is designed to study seed viability on the spoils and to study the Carex communities; their establishment, successional patterns, and composition. The Carex communities were sampled to determine the extent of difference between them and the surrounding unvegetative spoil material.

OBJECTIVES AND HYPOTHESES

There were four major objectives considered in this study. The first objective was to determine if there were viable seeds or plant propagules randomly scattered over the study area that could serve as a plant source. Soil samples were randomly collected from the study area and a greenhouse study was used to determine if viable seeds were present. This study tested the hypothesis that seeds of various plant species are available in the bare soil for natural revegetation of the mine.

The second objective of the study was to determine if native seedlings within the *Carex* communities have a greater percent survival than seedlings outside the *Carex* communities. Seedling survival data were collected during the growing season in the study area. The data were used to test the hypothesis that there is greater seedling survival within the *Carex* communities than outside the communities.

The third objective was to compare the vegetation within the *Carex* communities with that outside, but adjacent to them, in terms of species present, percent plant cover, litter, and bareground. Inclined point frame data were collected within and outside the *Carex* communities. These data were used to test the hypothesis that the vegetation within the *Carex* communities differ significantly than that outside and that the species compositition within the *Carex* communities increased in diversity as the size of the communities increases.

The fourth objective was to compare some of the microenvironmental factors within the Carex communities with those outside in terms of: soil temperature, soil water potential, soil water content, wind speed, soil surface temperature, solar radiation in the visible spectrum, soil pH, soil nitrogen, soil phosphorus, and soil potassium. Field studies were conducted to compare the microenvironmental factors within and outside the Carex communities. These studies tested the hypothesis that Carex communities alter these microenvironmental factors significantly from those outside the communities.

STUDY SITE

The study was conducted on the McLaren Mine (109° 59' W, 45° 04' N) at about 3000 m elevation, located in the Beartooth Mountains, Park County, Montana. The characteristic climate of the area includes short growing seasons of 60-70 days, with cool summer temperatures. Annual precipitation is between 1140 and 1525 mm, most of which occurs as snow during the months of September through June (Brown et al. 1976). The geology of the area is the result of an uplifted Pre-cambrian granitic block from which extensive sedimentary material have been eroded through glaciation and post-glaciation weathering (Loverling 1929, Hughes 1933, Spencer 1959).

Mining has taken place in the area since the 1880's, but the McLaren Mine has been inactive since the early 1950's. Prior to then, the McLaren was an active open-pit gold, silver, and copper mine. The residual overburden materials are composed of high concentrations of iron sulfides with infrequent limestone outcrops. The majority of the spoils are acidic.

The McLaren Mine is situated in a subalpine ecosystem composed of scattered stands of stunted Pinus albicaulis Engelm. and Abies lasiocarpa (Hook.) Nutt. with a forb-grass understory. The primary understory species include Antennaria lanata (Hook.) and Greene, Carex paysonis Clokey, Hieracium gracile Hook. and Carex nigricans Meyer at the upper boundaries of the mine and Juncus mertensianus

Bong., *Erigeron peregrinus* (Pursh) Greene, *Carex nigricans* Meyer and *Caltha leptosepala* DC. at the lower boundaries. The mine is located on a western exposure with about 30 percent slope in the headwater drainage of the Stillwater River. Acid water runoff from the mine has severely altered many of the downslope plant communities (Johnston et al. 1975).

The McLaren Mine disturbance covers an area of about 13.2 ha. Very little plant colonization has occurred since the mine was abandoned, and the majority of the disturbance is unvegetated. *Carex* communities located on the periphery of the disturbance are the most common vegetative cover. Several isolated *Carex* communities are scattered throughout the disturbance, and these *Carex* communities occur as nearly circular mats with diameters varying from 0.1 m to several meters across.

METHODS

Data were collected soon after snowmelt and continued through the first week of September, 1976 and 1977. In 1976, the area was not clear of snow until the third week of July. In 1977, precipitation was unusually low and the snow melted by the fourth week of June.

The field work for the seed viability study was completed in 1976. Laboratory and greenhouse tests were done in the fall of 1976 and spring of 1977. The field studies for the successional patterns of the local plant communities were completed in 1977.

An area of about 3.25 ha on the northeastern side of the mine was used to determine the viability of seed present on the disturbed site. The northeastern periphery of the mine was chosen to compare the characteristics of the *Carex* communities with the bare areas because it contained a relatively large number of *Carex* communities of varying size. An area 7 m by 70 m with fairly uniform soil type and slope (0-5 percent) was selected for intensive study. The uphill (eastern) boundary was bordered by undisturbed subalpine meadow dissected by talus slopes. The tip of one talus slope bordered 5 m of the successional patterns study area. The only trees near the study area were three *Pinus albicaulis* Engelm., 3-4 m high, located about 3 m into the meadow at one end of the study area. A map of the two study areas shows their relative positions (Figure 1).

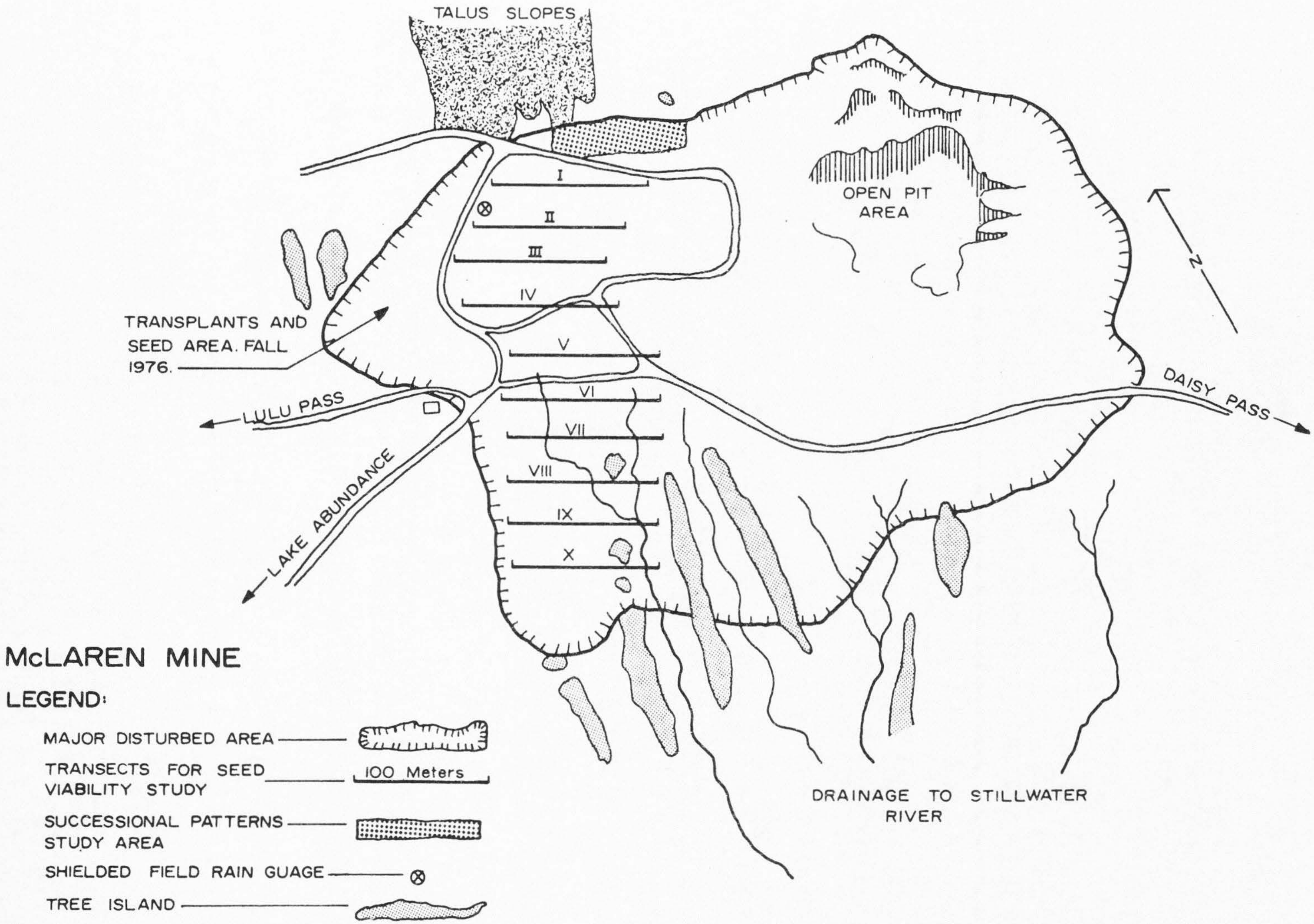


Figure 1. Map of the McLaren Mine disturbance showing the relative positions of the seed viability study area and the successional patterns studies area.

Seed Viability Study

In September 1976, samples were collected to determine the viability of seed which had blown onto the mine spoils. On the relatively uniform slopes of the northeast side of the mine, ten transects 100 meters long and 25 meters apart were established. Each began at the northeast side of the mine where there was undisturbed or slightly disturbed vegetation and extended southwest into the mine spoils. Ten plots were selected randomly along each grid line, but large rocks and water runoff areas were avoided. At each plot, the top 2 cm of soil was collected from an area 0.2 by 0.5 m. These 100 samples were transported to the Intermountain Forest and Range Science Laboratory at Logan, Utah, where they were air-dried in trays at greenhouse temperatures (18-26°C).

The samples were then gently crushed in a rubber lined bin to break down the aggregations. The samples were uniformly spread over the surface of sand-peat greenhouse mix (mixture ratio 2:3) in shallow trays. The trays were placed in the greenhouse with artificial lighting set for a 15 hour photoperiod and at greenhouse temperatures (18-26°C). The samples were watered at regular intervals to avoid surface drying. Once the seedlings began to emerge, the number and type (forb or graminoid) were recorded at regular intervals for 8 weeks. The seedlings were then grown to maturity.

Nearly all the seedlings reached maturity and flowered. Those that did not flower were identified to genus or to genus and species if such determinations could be made by vegetative characteristics. Specimens were preserved and verifications were made by A. H. Holmgren,

L. Schultz and F. Smith at the Utah State University Herbarium. Nomenclature, authorities and taxonomy follows Hitchcock and Cronquist (1973).

Successional Patterns Field Study

Descriptive data of the Carex communities and the surrounding bare areas were collected throughout the 1977 field season. A map of the study area on the northeastern periphery of the mine was made to describe the spacial distribution of the Carex communities. The location and diameter of each Carex community were recorded and they were classified in order of size by diameter. Three classes were selected based on the frequency distribution of diameter: class I: 10-30 cm diameter, class II: 50-70 cm diameter, and class III: 90-110 cm diameter. Carex communities that had diameters less than or greater than the designated classes were not used in the study. Nine Carex communities were randomly chosen from each class.

Paired observations were made to compare parameters measured within the Carex communities and the outside surrounding areas. Most of the area outside the Carex communities is void of vegetation but a few areas are sparsely vegetated with a few isolated plants or seedlings. These areas will be referred to as bare areas. One of the paired observations consisted of a chosen Carex community and the other consisted of a representative bare area adjacent to the Carex mat. For each selected Carex community, a bare area was designated to have the same size and shape. Adjacent Carex communities and bare areas were paired to minimize microenvironmental differences.

Collection of data for some of the parameters required partial destruction of the Carex communities or bare areas studied, therefore, the study area was divided into four sections for the collection of the following data:

Section 1. Seedling survival

Section 2. Soil temperature and water potential

Section 3. Soil water content

Section 4. Vegetation analysis, wind speed, radiation, surface soil temperature, and soil anlaysis.

Seedling survival

A total of 100 seedlings were located and marked within both the Carex communities and the adjacent bare areas in section 1 at the beginning of the 1977 field season. The seedlings were marked with small numbered stakes near the base of each plant. No attempt was made to identify the species of each seedling because of their small size, but they were comprised of graminoids with 1-4 leaves and Sibbaldia procumbens L. with 2-6 leaves. The number surviving were recorded each week throughout the season.

Vegetation analysis

A modified inclined point quadrat was used to obtain the vegetational data. The quadrat frame was 0.5 m by 1.0 m with pins at intervals of 10 cm. Fourteen gauge wire, 1.63 mm in diameter, was used for the pins. The quadrat frame was set at a 32.5°

incline, and one hundred points were recorded for each Carex community and each adjacent bare area. Two contacts were recorded: 1) the first contact of each pin with vegetation and 2) final contact of each pin with plant basal, bareground or litter.

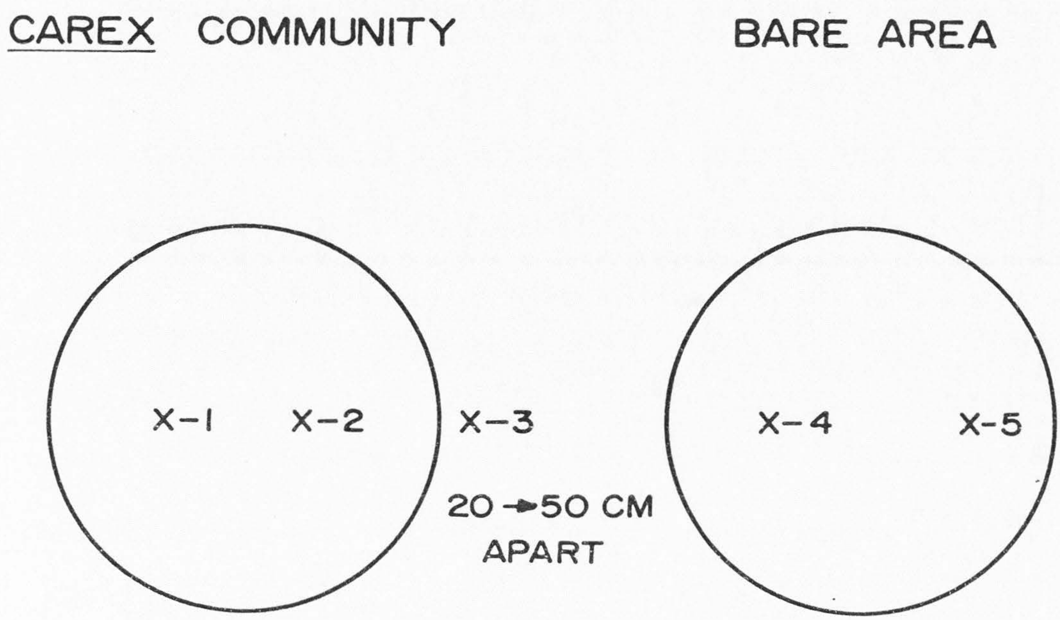
All species present in the Carex communities and bare areas were listed. Specimens of each species present were collected and identified.

Microenvironmental measurements

Microenvironmental measurements collected within the Carex communities and bare areas include: 1) soil temperature and soil water potential, 2) soil water content, 3) surface measurement of wind speed, radiation and surface soil temperature, and 4) soil analysis of pH, nitrogen, phosphorus, and potassium. Microenvironmental measurements recorded for the general study area included total precipitation, air temperature, relative humidity, and solar radiation.

Microenvironmental measurements were recorded at five locations within the Carex communities and bare areas (Figure 2): 1) at the center of the Carex communities, 2) at the edge of the Carex communities, 3) adjacent to the Carex communities (adjacent was defined as within 10 cm of the edge of the Carex communities), 4) at the center of the bare areas, and 5) at the edge of the bare areas.

Soil temperature and soil water potential. Screen caged, single junction thermocouple psychrometers (Brown 1970), were used to measure soil temperature and soil water potential in section 2.



X-1 <u>CAREX</u> COMMUNITY, CENTER
X-2 <u>CAREX</u> COMMUNITY, EDGE
X-3 <u>CAREX</u> COMMUNITY, ADJACENT
X-4 BARE AREA, CENTER
X-5 BARE AREA, EDGE

Figure 2. The five locations within the *Carex* community are the bare area where microenvironmental measurements were taken.

Six Carex communities and bare areas, two from each size class, were chosen for placement of the psychrometers. The psychrometers were cautiously buried at a depth of 5 cm in the soil to minimize community disturbance. A small trench was dug with a sharp knife to about 10 cm depth and the vegetation was removed intact where possible. One trench side was cut vertically and a small hole was then dug horizontally into the soil at 5 cm depth and the psychrometer inserted. The trench was refilled in an attempt to replace soil and vegetation as originally found. The psychrometer lead wires were left exposed for attachment to the psychrometer read-out meter (SB-Systems Model 600).

Soil temperature was recorded in °C and water potential was read in microvolts and later converted to bars. Field readings were taken between 12 noon and 1:30 p.m. throughout the field season.

Soil water content. Soil water content was measured gravimetrically by determining the water in soil samples collected in section 3. Five samples were collected from each of the six Carex communities and bare areas, two from each size class. At any one collection time, one sample was collected from each location from each size class. The samples were collected between 10:00 a.m. and 12 noon.

Vegetation and litter were removed and soil cores, about 5 cm in diameter, were taken to a depth of 0-5 cm. The samples were passed through a 2 mm mesh screen to remove major roots and rocks and put into air tight sample containers. Samples were similarly and quickly (approximately 3 minutes) collected to minimize moisture loss due to collection procedure. Samples were then weighed and air-dried. The soil water content samples were transported to Utah State University where they were weighed, oven-dried at 100°C for 48 hours, cooled and reweighed.

Wind speed, visible radiation, and soil surface temperature. Wind speed, radiation, and soil surface temperature data were collected from section 4. Samples were taken from fifteen *Carex* communities and bare areas, five pairs from each size class.

Wind speed was measured with a hot-wire anemometer (Hastings air meter Model RB-1) in miles per hour and later converted to kilometers per hour. The anemometer was placed at ground level at each location and readings were taken between 2:00 p.m. and 4:00 p.m.

Radiation in the visible portion of the spectrum (0.4 μ to 0.7 μ) was measured with a Lambda quantum sensor (Model LI-190S). Readings were recorded in microeinsteins m^{-2} sec^{-1}. The quantum sensor was placed at ground level at each location and readings were taken between 12 noon and 1:00 p.m.

Soil surface temperature was recorded with a copper-constantan (26 AW) thermocouple attached to the psychrometer read-out meter. The thermocouple wire was placed beneath the soil surface and allowed to adjust for 2 minutes before reading. Readings were taken between 2:00 p.m. and 4:00 p.m. and recorded in °C.

Soil analysis. Composite soil samples from a depth of 0-5 cm were taken from the 15 *Carex* communities and bare areas in section 4. When vegetation was present, it was removed and the soil shaken free from the roots. The large rocks were removed from all samples. Soil samples were taken only at the end of the field season.

The soil samples were air-dried and transported to the Utah State Soil, Plant, and Water Analysis Laboratory where they were analyzed, in duplicate, by standard techniques. Laboratory analysis of the fine (<2 mm) fraction included pH, nitrogen, phosphorus, and potassium.

Soil pH was determined on a saturated paste with a pH meter (Orion Res. Model 404). Nitrogen was determined as nitrifiable nitrogen, using microbial activity to release the mineral nitrogen. Soil samples were incubated under optimal conditions of aeration, temperature, and moisture for soil microbial activity for a period of two weeks. The amount of mineral nitrogen was measured before and after incubation by the chromatropic acid procedure (Haby and Larson 1976). Change in mineral nitrogen is taken as a measure of the nitrogen suppling capacity of the soil (Lamborn 1976).

Available phosphorus was determined by the dilute acid-fluoride method (Bray and Kurtz 1945, Jackson 1958). Extractable potassium was determined by ammonium acetate extraction followed by atomic absorption (Peech 1965).

Precipitation, air temperature, relative humidity and radiation. Precipitation for the field season was recorded from a shielded precipitation gauge, 20 cm in diameter and 3.7 m in height. The field gauge was located about 30 m southwest of the study area. The gauge was installed by the U.S. Forest Service, Intermountain Forest and Range Research Station, Logan, Utah, on September 8, 1976.

Air temperature and relative humidity were measured with a calibrated hygrothermograph (Belfrot, Ser. 1787). The hygrothermograph was placed in a white painted louvered shelter between 5 and 25 cm above the ground. It was located in a representative area of the study area. Readings were recorded continuously throughout the field season.

Solar radiation (0.3 μ to 3 μ) was measured with a calibrated pyroheliograph (Belfort, Ser. 1173). The pyroheliograph was secured to the top of the hygrothermograph shelter, and readings were recorded throughout the field season.

RESULTS AND DISCUSSION

A wide variety of viable seeds of several species were present in soil samples taken from the McLaren Mine. Both the seed viability and the successional patterns studies showed that there were adequate seeds and propagules present to vegetate the spoils if the seedlings could become established. A greater number of seedlings and species germinated in samples taken from lower elevations on the disturbance. Seedlings were observed in the spoils both in the vegetated areas and in the surrounding bare areas on the mine. The percent survival of seedlings were greater in the vegetated areas than the bare areas. The vegetated areas apparently alter microenvironmental factors and provide a microhabitat which encourages plant establishment and growth.

The vegetated areas were represented by Carex communities and altered the microenvironmental factors within the communities by reducing the harshness of the effects of wind speed, radiation, and soil temperature, and by providing a richer source of plant nutrients than adjacent bare areas. In larger Carex communities, the number of species present increased, percent litter cover increased, soil temperatures decreased, and the nitrogen and potassium levels in the soil increased. The effect of community development with increase in size can best be understood by comparing the interactions between location of the microenvironmental measurement within the community (center, edge, and adjacent), and size of community (small, medium, and large). All three locations appear to vary depending on the density and height of vegetation present.

Seed Viability Study

In laboratory and greenhouse tests, seedlings grew in 56 of the 100 soil samples collected, thus supporting the hypothesis that there are viable seeds of a wide variety of species available in the McLaren Mine spoils. A total of 331 seedlings germinated in the 56 samples and were composed of 22.1 percent forbs and 77.9 percent graminoids (grasses, sedges, and similar plants). Once the seedlings matured, 16 species were identified (Table 1). (Two of the genera, *Deschampsia* and *Carex*, are known to have pretreatment requirements for germination. Many alpine and subalpine plants are dormant, requiring pretreatment for germination or have low germination rates).

A number of seed viability and seed dormancy studies have been conducted with seeds collected from native plants in alpine and subalpine areas (Amen 1965, 1966, Bliss 1958, Bonde 1965a, 1965b, Clebach et al. 1976, Harrington 1946, Pelton 1956). None of these studies included seed from soil saples taken from natural or man-made disturbances.

Only a few species in this study were included in previous work. These species included *Poa alpina* L., reported with >50 percent germination with no pretreatment requirement, *Deschampsia cespitosa* L. Beauv, reported to have a scarification pretreatment to break dormancy, and *Sibbaldia procumbens* reported with <50 percent germination with no pretreatment requirement (Amen 1964).

Table 1. Number of seedlings of each species identified in the seed viability soil samples and their presence or absence by transect with decrease in elevation.

Number of Seedlings	Species	Species Present by Transect — Decreasing Elevation →									
		I	II	III	IV	V	VI	VII	VIII	IX	X
187	*Juncus drummodii* E. meyer	-	-	-	+	+	+	+	+	+	+
	Juncus hallii Engelm.	-	-	-	-	+	+	+	+	+	+
36	*Juncus mertensianus* Bong.	-	-	-	-	-	-	+	+	+	+
33	*Epilobium alpinum* L.	+	-	+	+	+	+	+	-	+	-
28	*Carex paysonis* Clokey	-	-	-	-	+	-	-	-	+	+
	Carex sp.	-	-	-	-	-	+	-	+	+	+
24	*Hieracium gracile* Hook.	-	-	-	+	-	+	+	-	+	+
7	*Arabis hirsuta* (L.) Scop.	-	-	-	+	-	-	-	-	-	-
6	*Deschampsia cespitosa* (L.) Beauv	+	+	-	+	-	-	+	-	-	-
2	*Arabis lyallii* S. Wats.	-	-	-	-	-	-	-	-	+	-
2	*Sibbaldia procumbens* L.	-	-	-	-	+	-	-	+	-	-
2	*Poa alpina* L.	-	-	-	-	-	-	-	+	+	-
1	*Antennaria lanata* (Hook.) Greene	-	-	-	-	-	-	-	-	-	+
1	*Epilobium angustifolium* L.	-	-	-	-	+	-	-	-	-	-
1	*Ranunculus eschscholtzii* Schlecht	-	-	-	-	-	-	+	-	-	-
1	*Sagina saginoides* (L.) Britt.	-	-	-	-	-	+	-	-	-	-
331	Total number of seedlings										
	Total number of species per transect	2	1	1	5	6	6	7	6	9	7

A study by Bliss (1958) of 26 alpine species included Poa alpina and Sibbaldia procumbens. In his study, seeds were frozen for six to seven months then placed under light and dark laboratory conditions to test germination. Poa alpina had a 83.5 percent germination rate under light and a 91.2 percent germination rate under dark conditions. Sibbaldia procumbens had a 44.0 percent germination rate under light and 43.3 percent germination rate under dark conditions. Many alpine Carex species require scarification or other types of pretreatment to break dormancy (Amen and Bonde 1964).

In the present study, Deschampsia cespitosa and Carex germinated with no pretreatment. Unintentional scarification may have occurred during preparation of soil samples by crushing of aggregations. This would explain the presence of seedlings of both Deschampsia cespitosa and the two species of Carex.

The presence of seedlings of normally dormant species in the samples indicates that there may be a greater number of seeds of these plants and other dormant species available in the spoils.

There appears to be a relationship between the number of viable seeds and the location of where the sample was collected on the mine. The number of seedlings per transect increased with decreasing elevation on the disturbed area. The transects were ranked using Kendahl's "tau" (Siegel 1956) to determine if there was a similarity between theoretical ranking and actual ranking of number of seedlings per transect and elevation of the transect. The theoretical and actual conditions were almost identical ("tau" = 0.7191, $p<1$ percent) (Table 2). The number of seedlings per plot by transect did not

Table 2. Actual rank score (S) for each plot position and combination of all plot positions by transect with decrease in elevation. Probabilities (p) associated with observed values of S and the Kendahl rank correlation coefficients ("tau") are presented.

	Plot Position per Transect	S	"tau"	p
Decreasing Elevation	1	3	0.0767	0.431
	2	16	0.3771	0.093
	3	24*	0.5657	0.019
	4	23*	0.5637	0.023
	5	22*	0.5624	0.030
	6	27*	0.6617	0.008
	7	25*	0.6299	0.014
	8	27*	0.7006	0.008
	9	20*	0.4837	0.045
	10	5	0.1297	0.364
	All plot positions	32	0.7191	0.002

*S $\geq$ 20 is significant at p $\geq$ 5%.

increase with increasing distance from undisturbed plant communities at the same elevation (Table 3). The number of species per transect also increased with decreasing elevation on the disturbed area ("tau" = 0.7070, $p<0.1$ percent).

The seed source apparently originates from undisturbed subalpine meadows that surround the boundaries of the McLaren Mine and from isolated plant communities located on the periphery of the mine. Seeds are apparently distributed by westerly winds which move across the valley floor and up the mountain slopes across the mine. Apparently, the winds deposit a greater proportion of seeds on the lower elevations of the spoils than on the higher elevations. Other factors that may influence seed distribution on the spoils are weight of seeds, yearly seed production, and other mechanisms of seed dispersal. The distribution of seeds on the spoils may also be influenced by the surface characteristics of the spoils which vary considerably in rockiness, slope, and soil texture. The variation in surface characteristics would effect the number of niches available for catchment of seeds.

Successional Patterns Field Studies

Three separate studies of successional patterns in *Carex* communities were conducted: Seedling survival, vegetational analysis, and microenvironmental measurements.

Seedling survival

Seedlings were present in both the established vegetation and the bare areas on the study site. There was a greater percent

Table 3. Rank score (S) for each transect and combination of all transects with increase in distance from undisturbed tundra at the same elevation. Probabilities (p) associated with observed values of S and the Kendahl rank correlation coefficients ("tau") are included.

Decreasing Elevation

Transect	S	"tau"	p
I	12	0.4472	0.168
II	-7	-0.2277	0.300
III	6	0.2236	0.332
IV	-4	-0.1217	0.398
V	34*	0.8014	0.001
VI	9	0.2268	0.242
VII	-2	-0.0471	0.465
VIII	16	0.3869	0.093
IX	16	0.3596	0.093
X	-20*	-0.4600	0.045
All transects	3	0.0682	0.431

*S $\geq$ 20 is significant at p $\geq$ 5%.

survival of seedlings within the Carex communities than in the surrounding bare areas. During the 1977 growing season 71 out of 100 marked seedlings survived within the Carex communities. Only 46 of 100 marked seedlings were alive in the surrounding bare areas at the end of the 1977 field season. Thus the hypothesis that greater seedling survival occurs in the Carex communities was accepted. The binomial statistical test showed a significantly greater ($p<0.1$ percent) number of live seedlings in the Carex communities than on the surrounding bare areas. The χ^2 approximation was 11.863 with 1 d.f.

Weekly counts of the number of surviving seedlings in the two locations are recorded in Figure 3. There was no significant differences in the percent survival between the two populations until after August 25. On August 25 and 26, 20-26 cm of snow fell on the mine, and air temperatures remained low between August 25 and 30 with means of 2.8±3.3°C. However, the snow melted from the area by August 29, and during the September 2 seedling count, it was noted that the soil surface showed signs of disturbance by frost action. Many of the roots of seedlings had been pulled out of the soil by frost action in the bare areas outside the Carex communities, but there was little sign of frost action within the Carex communities.

The main cause of death in the bare areas was attributed to frost action. Ellison (1949) made the same observation in a similar study in disturbed subalpine tundra in the Uinta Mountains. He found that frost action on bare areas greatly increased seedling mortality and that vegetated areas provided greater seedling protection.

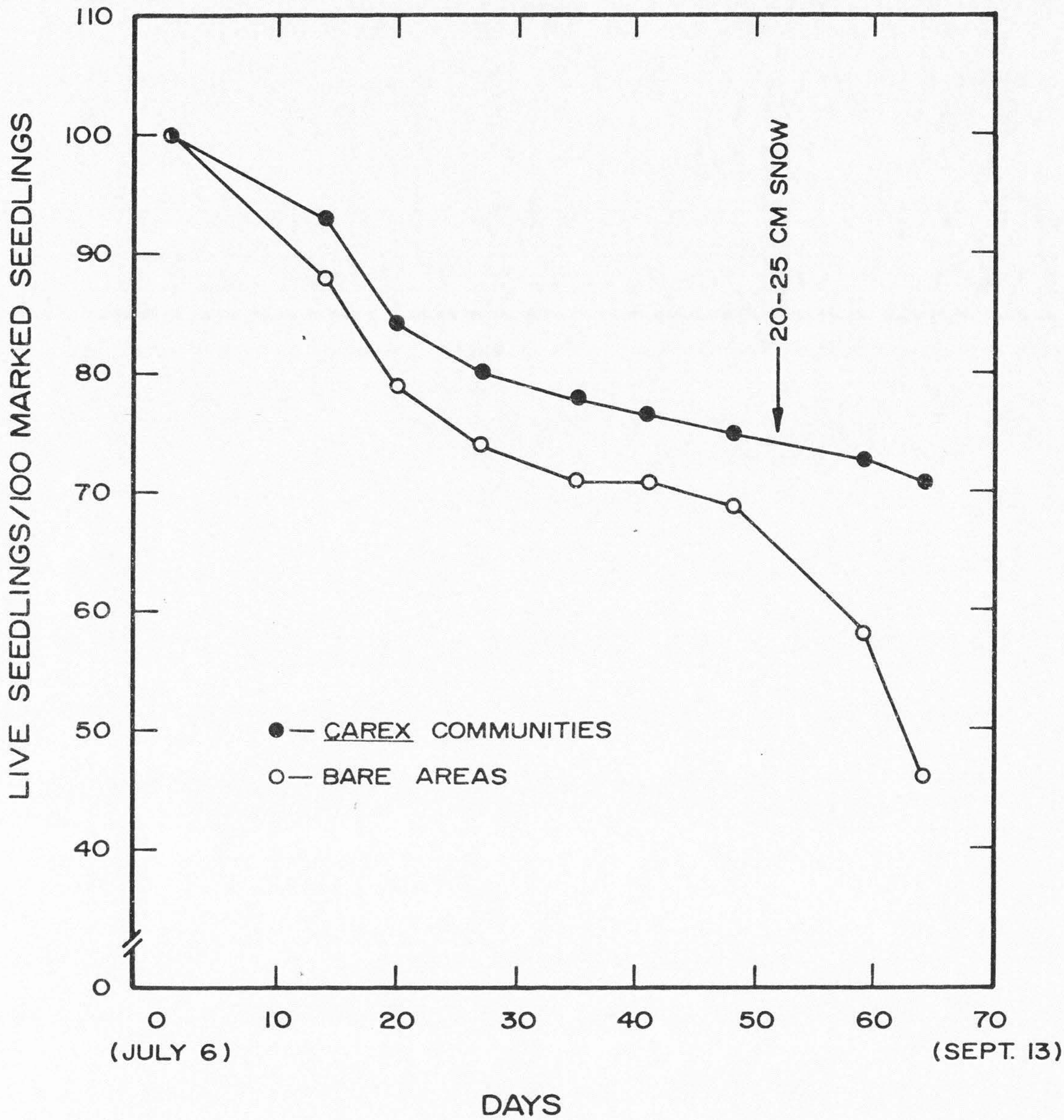


Figure 3. Number of live seedlings per 100 marked seedlings by days during the 1977 field season in <u>Carex</u> communities and in bare areas.

The presence of vegetation in disturbed areas apparently ameliorates the microenvironment sufficiently for seedling establishment. Willard and Marr (1971) reported that in alpine tundra disturbed by man, the most favorable place for seedlings to develop was along margins of established plants.

Seedling desiccation due to low soil water was not considered a major cause of seedling mortality. Precipitation for the 1977 field season was unusually high (349 mm) and was distributed by frequent storms throughout the season. In seasons with low precipitation, low soil water is a major factor contributing to seedling mortality. Van Kekerix (1977), however, reported desiccation on the McLaren Mine as a major contributing factor to seedling mortality. During that period (1976) there was 97 mm of precipitation during the period of August to early September. Seedling survival over several seasons may also involve other factors. Bonde (1968) suggested that low carbohydrate production may be the primary cause of high death rates of seedlings over a period of several seasons.

Vegetational analysis

The vegetation within the Carex communities and the outside surrounding bare areas differ significantly as to species present, percent vegetative cover, litter cover, and bareground. The species composition within the Carex communities increased in diversity as the size of the Carex communities increased. Therefore, the third hypothesis is accepted and vegetation within the Carex communities differ significantly from that outside. Also the species composition within the Carex communities increased in diversity as the size of the communities increases.

Twelve species were present within the Carex communities. Only one species was present in the surrounding bare area (Table 4).

Percent crown cover (Table 5) and percent basal cover (Table 6) were determined within the Carex communities and the bare areas. Percentage composition for each species was determined from the vegetation cover data.

The percent crown cover was 84.34 in the Carex communities and 0.0 in the bare areas. The litter and bareground was 15.66 percent in the Carex communities, of which litter made up 7.13 percent and bareground, 8.53 percent. The bare areas had 0.6 percent litter and 99.4 percent bareground.

The percent basal cover, litter cover, and bareground data reflected the same relationship between the Carex communities and the bare areas as the crown cover data. Total percentage basal cover was 17.0 percent in the Carex communities and 0.07 percent in the bare areas. Litter cover was 46.07 percent and 0.60 percent, respectively, in the Carex communities and bare areas. Bareground was 36.87 percent in the Carex communities and 99.33 percent in the bare areas.

The species present within the Carex communities were used as a relative measure of increase in diversity as the Carex communities size class increased. The percent litter cover was used as an indicator of increase in community development. There were 4, 6, and 8 species present for small, medium, and large communities, respectively. This indicated a change in diversity as measured by number of species for a given community. The litter cover was 34.2

Table 4. Species presence (+) or absence (-) in the Carex communities and the bare areas by size class. Species occurrence within replicates are presented.

Species	Class I Replicates 1 2 3 4 5	Class II Replicates 1 2 3 4 5	Class III Replicates 1 2 3 4 5
I. Carex Communities			
Carex paysonis Clokey	+ + + + +	+ + + + +	+ + + + +
Sibbaldia procumbens L.	- + + + -	+ + - - -	- + + - +
Deschampsia altropurparea (Wahl.) Scheele	- - - + -	- - - - -	- - - - -
Phleum alpinum L.	- - - - -	+ - - - -	- - - + -
Trisetum spicatum L. Richter	- - - - -	+ + - - -	- - - + +
Epilobium angustifolium E. Meyer	- - - - -	+ - - - -	- - - - -
Antennaria lanata (Hook.) Greene	- - - - -	- - - - -	- - - - +
Juncus drummondia E. Meyer	- - - - -	- - - - -	- - - - +
Polybonium bistortoides Pursh	- - - + -	- - - - -	- - - - -
Hieracium gracile Hook.	- - - - -	+ - - - -	- - - - +
Epilobium alpinum L.	- - - - -	+ - - - -	- - - - -
Selaginella sp.	- - - - -	- - - - -	- - - - +
Total number species/class	4	6	8
II. Bare Areas			
Erigeron peregrinus (Pursh) Greene	- - - - -	- - - - -	+ - - - -
Total number of species per class	0	0	1

Table 5. Percent cover and composition of crown area, litter, and bareground within the <u>Carex</u> communities and the bare areas. The number of replications for each class was five.

Species	Class I		Class II		Class III		All Classes	
	Percent cover	Percent composition	Percent cover	Percent composition	Percent cover	Percent composition	Percent cover	Percent composition
I. <u>Carex</u> Communities								
<u>Carex</u> <u>paysonis</u> Clokey	70.0	83.14	82.8	97.18	80.0	95.69	77.60	92.02
<u>Sibbaldia</u> <u>procumbens</u> L.	11.4	13.54	0.2	0.24	1.0	1.20	4.20	4.98
<u>Deschampsia</u> <u>altropurpurea</u> (Wahl.) Scheele	2.8	3.32	0	0	0		0.93	1.10
<u>Phleum</u> <u>alpinum</u> L.	0		0.6	0.70	1.8	2.15	0.80	0.95
<u>Trisetum</u> <u>spicatum</u> L. Richter	0		0.8	0.94	0.4	0.48	0.40	0.77
<u>Epilobium</u> <u>angustifolium</u> L.	0		0.6	0.70	0		0.20	0.24
<u>Antennaria</u> <u>lanata</u> (Hook.) Greene	0		0		0.2	0.24	0.07	0.08
<u>Juncus</u> <u>drummondii</u> E. Meyer	0		0		0.2	0.24	0.07	0.08
<u>Epilobium</u> <u>alpinum</u> L.	0		0.2	0.24	0		0.07	0.08
Bareground and rock	9.2		8.0		8.4		8.53	
Litter	6.6		6.8		8.0		7.13	
Total vegetation cover	84.2	100.0	85.2	100.0	83.6	100.0	84.34	100.00
II. Bare Areas								
Bareground and rock	99.2		100.0		99.0		99.4	
Litter	0.8		0		1.0		0.6	
Total vegetation cover	0.0	0	0	0	0	0	0	0

Table 6. Percent cover and composition of basal area, litter, and bareground within the Carex communities and the bare areas. The number of replicates for each class was five.

Species	Class I		Class II		Class III		All Classes	
	Percent cover	Percent composition	Percent cover	Percent composition	Percent cover	Percent composition	Percent cover	Percent composition
I. Carex Communities								
Carex paysonis Clokey	10.8	72.00	12.2	84.72	19.0	87.96	14.00	82.35
Sibbaldia procumbens L.	4.0	26.67	1.2	8.33	0.6	2.78	1.93	11.35
Phleum alpinum L.	0.0		0.4	2.78	0.2	0.93	0.20	1.18
Trisetum spicatum L. Richter	0.0		0.2	1.39	0		0.07	0.41
Juncus drummondii E. Meyer	0		0		0.2	0.93	0.07	0.41
Polygonum bistortoides Pursh	0.2	1.33	0		0		0.07	0.41
Hieracium gracile Hook.	0		0		0.6	2.78	0.20	1.18
Epilobium alpinum L.	0		0.4	2.78	0		0.13	0.76
Selaginella sp.	0		0		1.0	4.62	0.33	1.95
Bareground and rock	50.8		35.4		24.4		36.87	
Litter	34.2		50.2		54.0		46.07	
Total vegetation cover	15.0	100.00	14.4	100.00	21.6	100.00	17.00	100.00
II. Paired Area								
Erigeron peregrinus (Pursh) Greene	0	0	0	0	0.2	100.00	0.07	100.00
Bareground and rock	99.2		100.0		98.8		99.33	
Total vegetation cover	0	0	0	0	0.2	100.00	0.07	100.00

percent, 50.2 percent, and 54.0 percent, respectively, for small, medium, and large communities.

Carex paysonis dominated all the Carex communities regardless of size. It is a co-dominant species with Antennaria lanata, Heiracium gracile, and Carex nigricans in the undisturbed subalpine meadow located near the study area. Sibbaldia procumbens was the only other species that had a representative cover in all three size classes in both crown and basal cover. In one small Carex community, Sibbaldia procumbens was a co-dominant (43 percent crown cover) with Carex paysonis (48 percent crown cover). All the other species had a crown cover value <2 percent.

Although some of the vegetation on the mine may have originated from wind blown seeds and other propagules, it appears that most of the vegetation had become established through vegetative propagules transported during mining activities. Several islands of vegetation in the study area originated from clumps of vegetation that had broken off the undisturbed vegetation slope and had established their roots in the flatter surface on the disturbed area.

The Carex communities represent one type of pioneer vegetation and initial stages of primary succession on mine spoils.

The presence of very little vegetation cover in the bare areas after more than 20 years of colonization indicated that natural revegetation of mine spoils is a very slow process on drastically disturbed tundra. No precise time interval can be estimated for the vegetational recovery of disturbed areas in subalpine regions. Willard and Marr (1971) stated it would take at least several hundred years for ecological processes to produce a climax ecosystem in drastically disturbed alpine ecosystems. Although seeds and seedlings are present on the spoils, the severe microenvironmental conditions greatly reduce chances of seedlings surviving to maturity.

The rhizomous growth habit of Carex species appear to be one of the major contributing factors to it's success as a colonizing species. Once the Carex plant is firmly established in the spoils, it apparently expands its growth into adjacent spoils by rhizomes. The three size classes of Carex communities studied were representative of the majority of the circular communities in the study area. There were relatively large communities (several meters in length), consisting of several circular Carex communities whose boundaries had joined, but these were not included in the study.

The general structure of the Carex communities appears to change with increase in community size. Small communities generally had the tallest and most dense vegetation in the center of the mat. Medium sized communities had the tallest and thickest vegetation located on the periphery of the community with the live vegetation less or absent at the center, leaving relatively large areas of litter unshaded by the canopy. In large communities, the tallest and thickest vegetation was also located on the periphery of the communities, whereas center vegetation (which included broad leafed forbs) was fairly uniform in height and distribution with small areas of exposed litter.

Microenvironmental measurements

Carex communities in the disturbed area significantly altered the microenvironmental factors of soil temperature, wind speed, radiation, soil nitrogen, and potassium to differ from the surrounding bare areas. The Carex communities appeared to have little or no effect in altering soil water potential or water content, pH, or soil phosphorus, therefore, the fourth hypothesis is partially supported and partially negated and must be restated.

Microenvironmental factors measured in the Carex communities differed significantly from the bare areas in that: soil surface temperature and soil temperature at 5 cm depth were cooler, wind speed and radiation flux were less, and there were greater amounts of nitrogen and potassium available in the soil.

The statistical test of analysis of variance was used to test the differences in the microenvironmental factors measured in the Carex communities and in the bare areas and to test microenvironmental differences between Carex communities as they increased in size. It was necessary to do a multiple split-plot analysis of variance to include the following variables: Carex communities or bare areas, size class I, II, or III, and location of microenvironmental measurement, center, edge, or adjacent. Only factors measured in the center and edge locations were used for comparisons in testing differences between Carex communities and bare areas. Center, edge, and adjacent locations were used in testing differences between size class within the Carex communities.

Soil temperature and water potential. The mean soil temperature at 5 cm depth was significantly cooler within the Carex communities

(11.48°C) than in the bare areas (13.52°C) for all size classes and locations ($p<5$ percent). The greatest differences in mean soil temperature was in medium sized communities (class II, 50-70 cm diameter) ($p<2.5$ percent). The differences decreased in large communities (class III, 90-110 cm diameter) ($p<5$ percent) and there was no significant differences in small communities (class I, 10-30 cm diameter). Mean soil temperatures in _Carex_ communities were cooler at the center (11.59°C) and edge (11.37°C) location than were the bare areas at the center (14.18°C) and edge (12.87°C) locations (Figure 4). It appears that the _Carex_ vegetation and litter cover act to insulate the soil from incoming radiation. Ballard (1972) also found higher temperatures (at 5 cm depth) in bare areas than in areas with vegetative cover in his study in subalpine tundra.

The mean soil temperatures at 5 cm did not vary significantly with increase in _Carex_ community size although mean soil temperatures were 2 to 2.5°C cooler in medium (10.81°C) and large (11.33°C) sized communities than small communities (13.30°C). The mean soil temperatures of small _Carex_ communities were closer to mean soil temperatures of bare areas (13.52°C) than either medium or large communities. Within the _Carex_ communities, mean soil temperatures were cooler at the center and edge locations than at the adjacent location (within 10 cm of the edge of the communities). Apparently the vegetative cover at the center and edge locations provided a greater protection from incoming radiation than the overhanging canopy of _Carex_ vegetation at the adjacent location (Figure 4).

The extent of the heat damping capacity of the surface cover appears to be related to the amount of area covered and composition

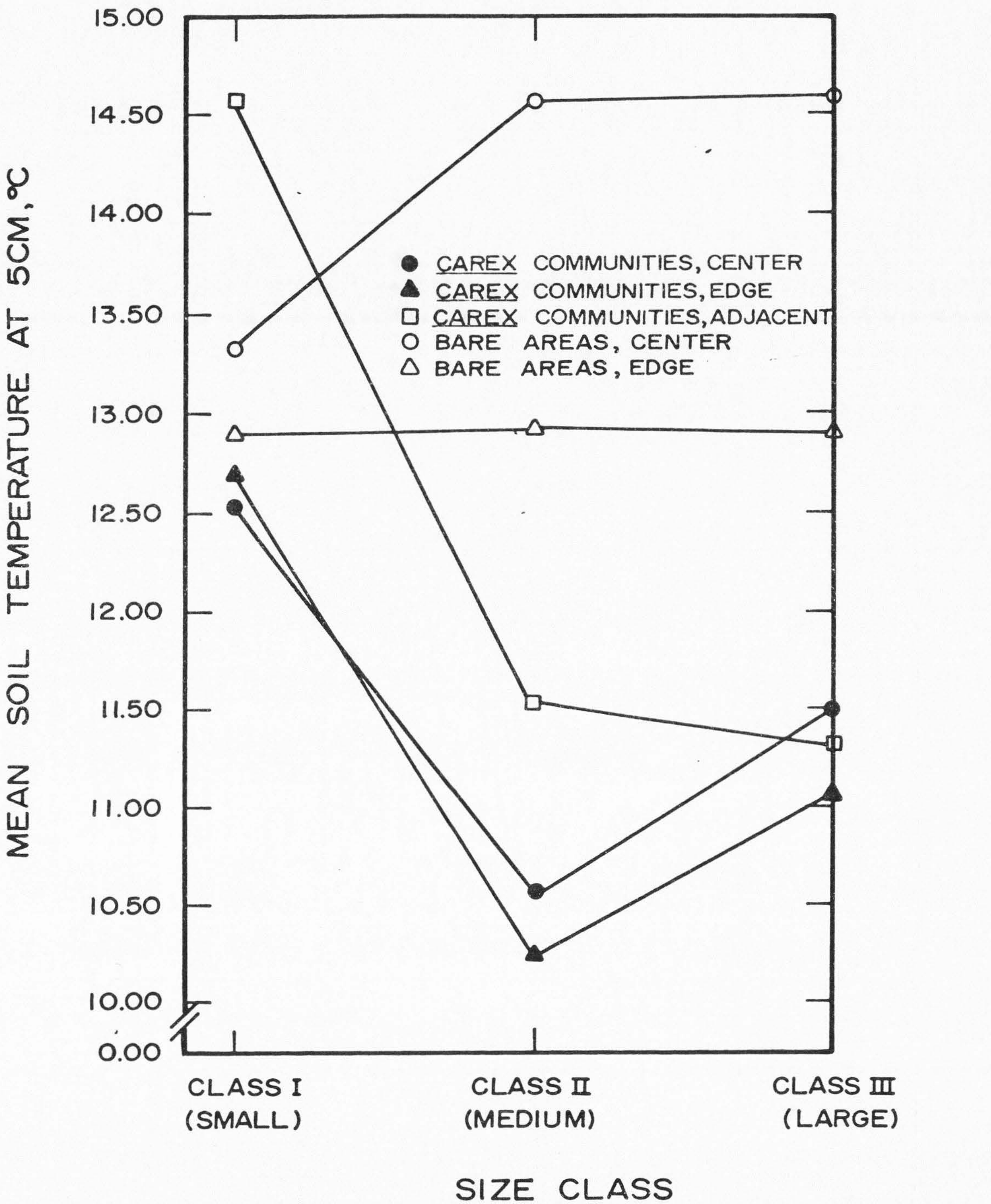


Figure 4. Mean soil temperature (°C) at 5 cm depth at the center, edge, and adjacent locations in the *Carex* communities and at the center and edge locations in the bare areas for size classes I, II, and III.

of it. Vegetation intercepted incoming radiation energy and shaded the soil, reducing the heat energy available for conduction into the soil. Litter has a high capacity for absorption of radiation energy and a low termal conductivity (Rosenburg 1974) which reduced the amount of heat conducted into the soil.

Mean soil water potential was significantly lower ($p<10$ percent) in the Carex communities (-1.04 bars) than in the bare areas (-0.47 bars), indicating slightly drier conditions in the vegetated areas. The greatest differences between the Carex communities and the bare areas occurs in the small pairs ($p<2.5\%$). There was no significant differences in medium and large pairs. The differences between the two areas decreased with increase in size class (Figure 5).

Within the Carex communities, mean soil water potential changed significantly with increase in community size ($p<10$ percent). The main differences occurred between small communities and both medium and large communities ($p<2.5$ percent). There was no significant difference between medium and large communities and between the center, edge and adjacent locations within the same community size class.

The mean soil water potentials recorded for all the Carex communities and the bare areas measured were not sufficiently low to provide a condition stressful to plant growth. Summer precipitation was high in 1977 (349 mm) with storms rarely greater than four days apart, even during the month of August, which is typically a dry period in the subalpine region studied. Gravimetric water content measurements also reflected a moist soil environment.

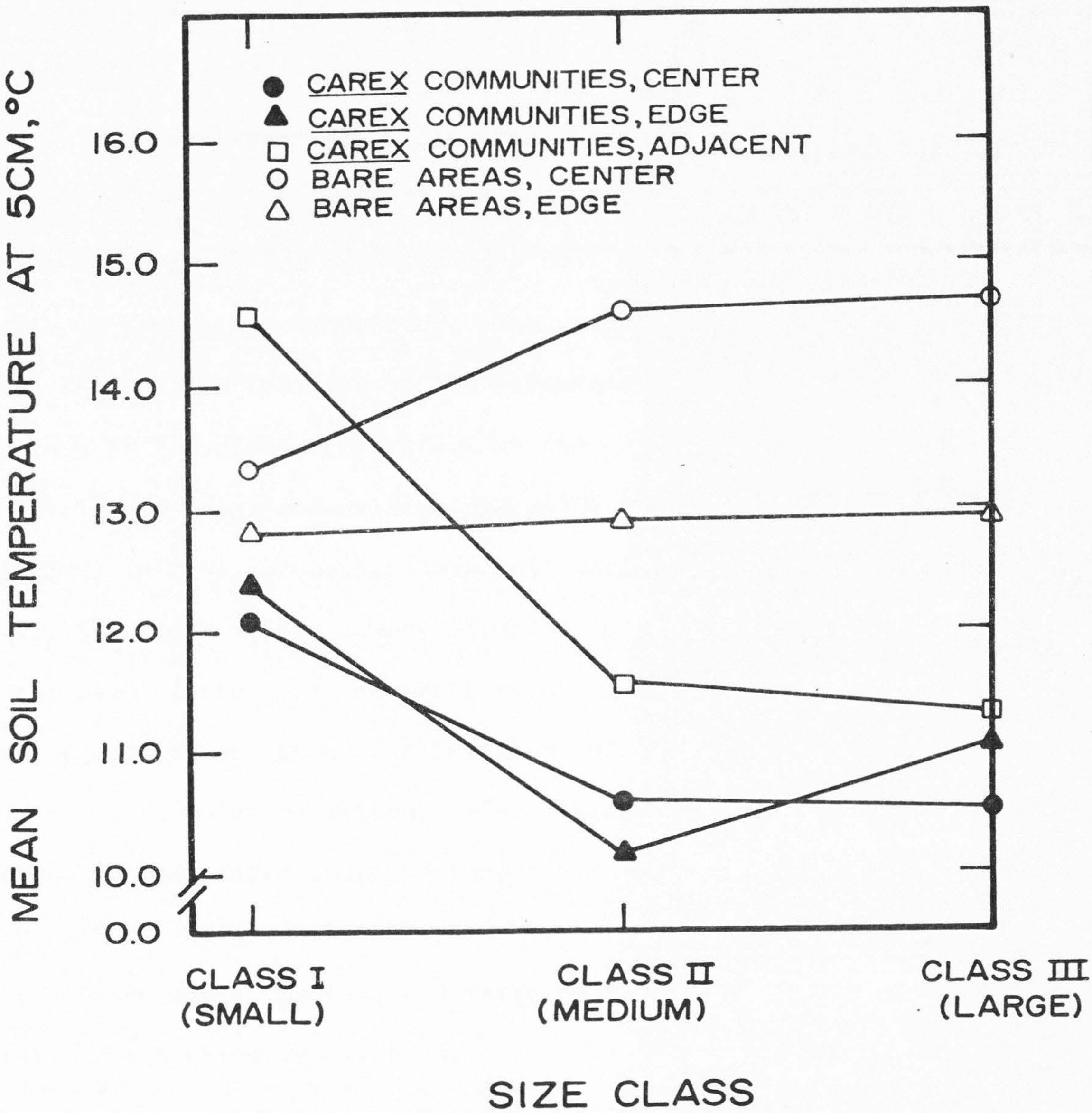


Figure 5. Mean water potential (bars) at 5 cm depth within *Carex* communities and bare areas for size classes I, II, and III.

Soil water content. The mean percent water content did not vary significantly between the *Carex* communities and the bare areas or with increase in community size within the *Carex* communities.

Soil surface temperature. Mean soil surface temperatures were significantly cooler ($p<10$ percent) in the *Carex* communities (20.10°C) than in the bare areas (21.5°C). The greatest differences occurred in small pairs ($p<2.5$ percent) and no differences occurred in either medium or large pairs, although mean soil surface temperatures were cooler in the *Carex* communities. The greatest differences were found between the location of the measurements within the two areas. The mean soil surface temperature at the edge location was much cooler in the *Carex* communities (18.53°C) than in the bare areas (21.37°C) ($p<0.05$ percent). Mean soil surface temperatures were nearly identical at the center location in the two areas. Vegetation at the edge of the *Carex* communities was usually taller and thicker than vegetation at the center location, offering greater protection from incoming solar radiation. Also, larger areas of litter were exposed in the center location than the edge location, absorbing more radiant energy. The relationship of mean soil surface temperature between small, medium, and large pairs, and center and edge locations are shown in Figure 6.

The mean soil surface temperature did not vary significantly with increase in community size. The mean soil surface temperature varied greatly between the center and edge location with community size (Figure 7).

Surface radiation. The mean radiation flux density measured in microeinsteins at the soil surface was significantly less in the

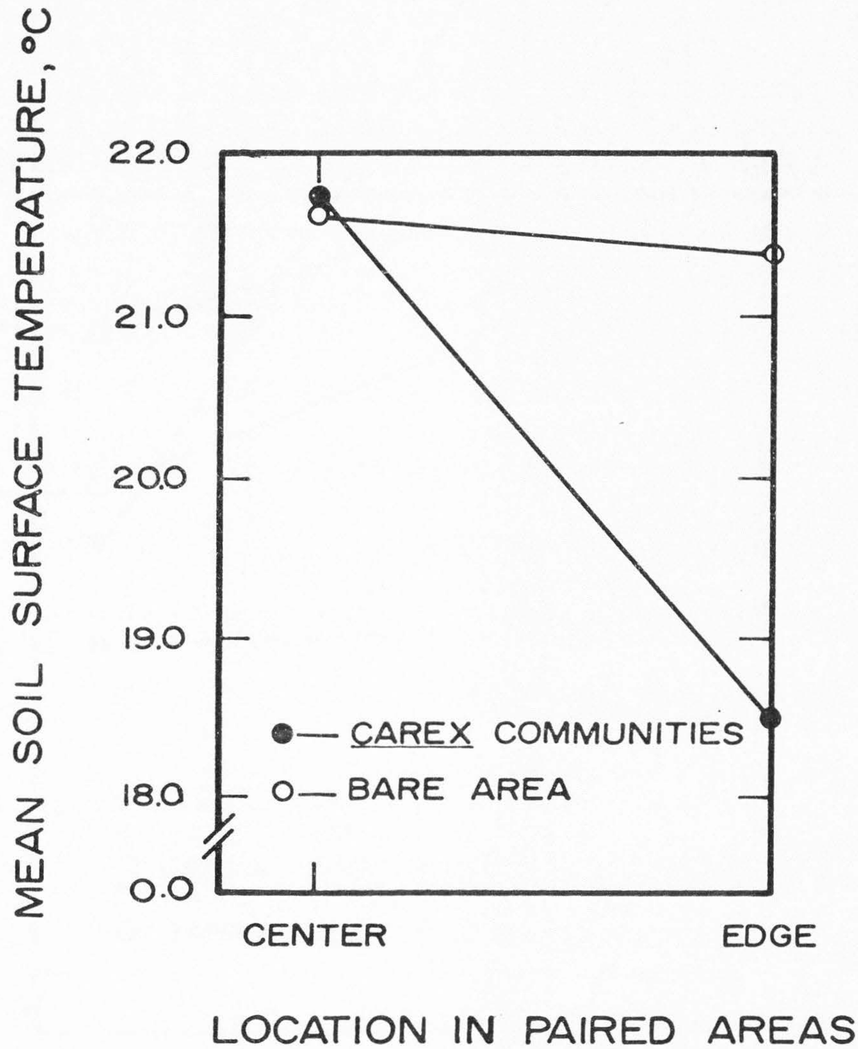


Figure 6. Mean soil surface temperature (°C) within Carex communities and bare areas at the center and edge locations.

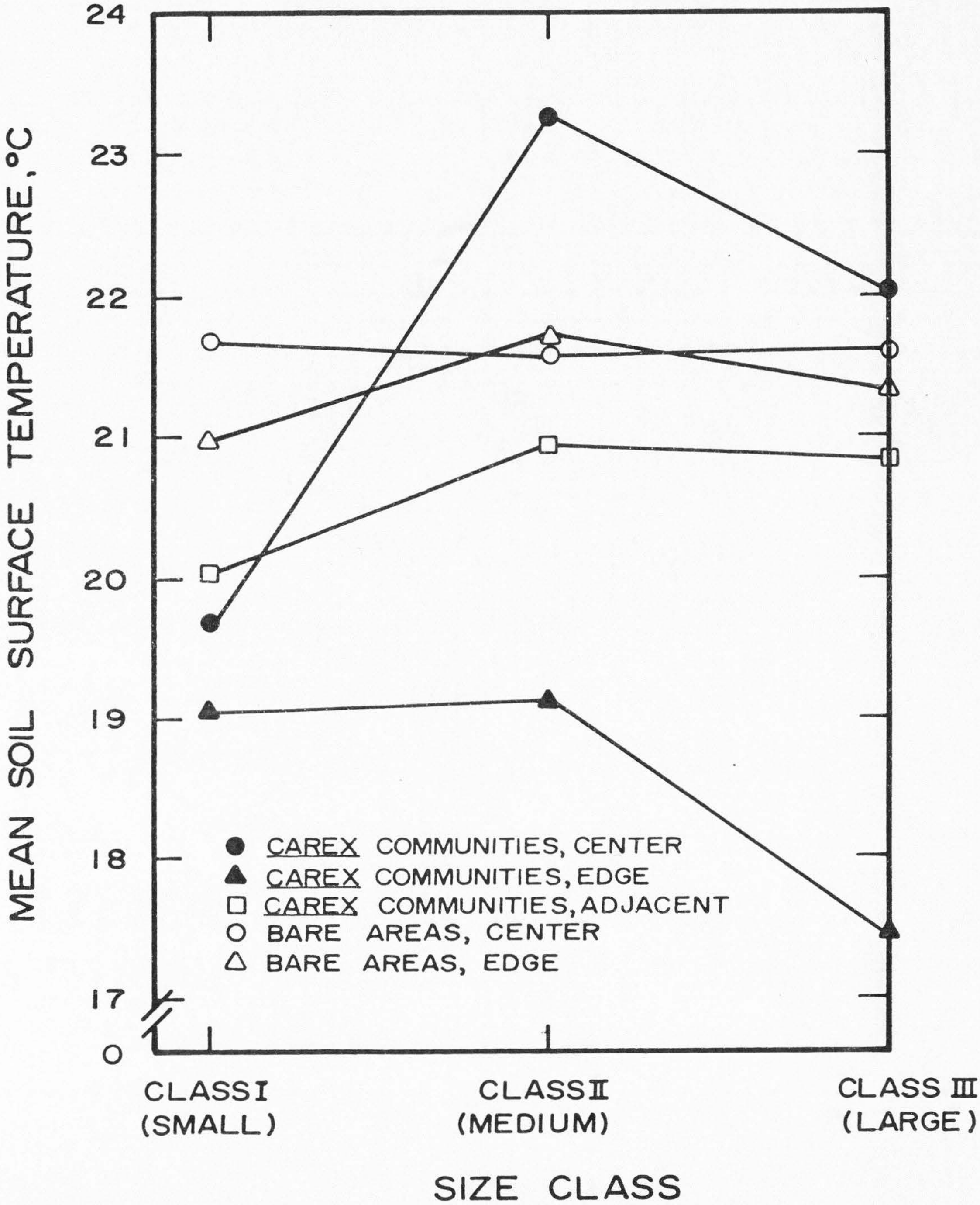


Figure 7. Mean soil surface temperature (°C) at the center, edge, and adjacent locations within the Carex communities, and at the center and edge locations in the bare areas for size classes I, II, and III.

Carex communities (3.49 microeinsteins m^{-2} sec^{-1}) than in the bare areas (5.74 microeinsteins m^{-2} sec^{-1}) ($p<0.5$ percent). The mean radiation flux density was significantly greater in the bare areas at the center (5.72 microeinsteins m^{-2} sec^{-1}) and the edge (5.77 microeinsteins m^{-2} sec^{-1}) locations than the Carex communities at the center (3.93 microeinsteins m^{-2} sec^{-1}) and edge (3.04 microeinsteins m^{-2} sec^{-1}) locations ($p<0.05$ percent). These relationships reflect the effect of the vegetative cover in reducing radiation load at ground level. The variation in mean radiation flux density at the center and edge location between the two areas with increase in size class is shown in Figure 8.

There was no relationship between amount of radiation flux density and the size of Carex community. There was a definite difference in mean radiation flux density with location of the measurement within the communities ($p<0.05$ percent) (Figure 8). The physiognomy of the communities apparently directly affected the relationship of mean radiation flux density with location of measurement within the community. Small communities generally had taller vegetation at the center. The medium sized communities frequently had little vegetation in the center, and the large communities usually had an even distribution of vegetation at the center. Edge vegetation appeared to become denser with increase in community size.

Surface wind speed. Mean wind speed within the Carex communities (1.46 km hr^{-1}) was significantly less ($p<0.05$ percent) than the mean wind speed (2.88 km hr^{-1}) within the bare areas. The relationship of the mean wind speed between the two areas remained similar for the three size classes.

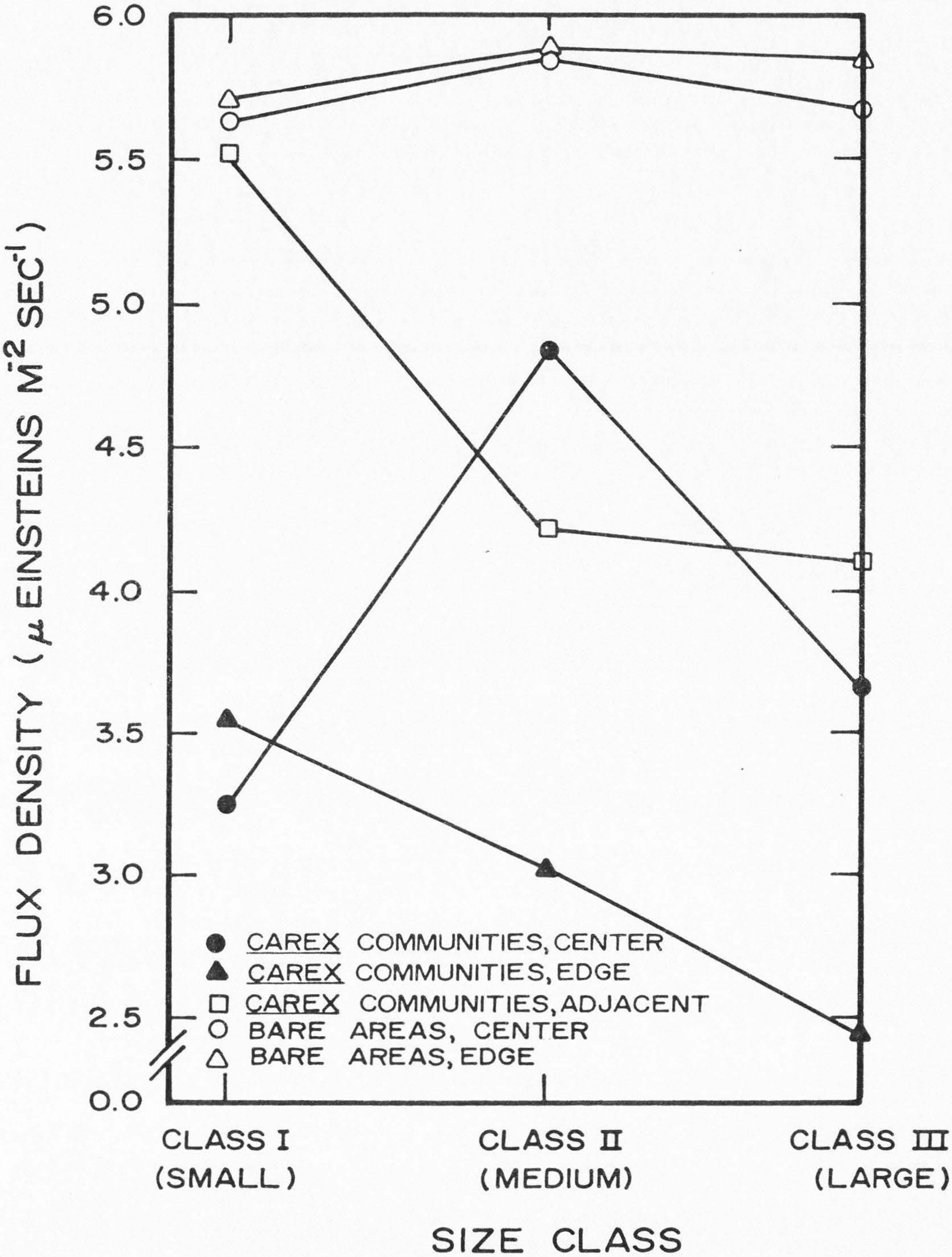


Figure 8. Mean radiation flux density (microeinsteins m^{-2} sec^{-1}) at the center, edge, and adjacent locations in the Carex communities, and at the center and edge locations in the same areas for size classes I, II, and III.

The mean wind speed did not change significantly with increase in Carex community size but the mean wind speed varied significantly ($p<0.05$ percent) between the center, edge, and adjacent locations (Figure 9).

It appears that the wind speed was buffered by the physical barrier of the vegetation within the Carex communities. The mean wind speed in the border vegetation of the Carex communities was greater than those measured at the center of the communities. Tranquillini (1964) reported that with long exposure to wind, the water status of the leaves is impaired, leading to a narrowing of the stomatal opening and a reduction in transpiration, CO_2 uptake, and dry weight production. Also, wind action increases the removal of top soil in exposed habitats of high elevation communities (Spomer 1964). By reducing mean wind speed, Carex communities reduced the severity of the microenvironment.

Soil pH, nitrogen, phosphorus, and potassium. The mean nitrifiable was 6.73 ppm within the Carex communities and 5.98 ppm for the bare areas. The difference between the paired areas did not vary significantly between small pairs and medium pairs. The mean nitrifiable nitrogen was significantly ($p<0.5$ percent) higher in the large Carex communities (10.60 ppm) than in the bare areas (6.05 ppm).

Mean nitrifiable nitrogen increased with increase in community size, with the greatest difference ($p<5$ percent) between the small communities and the large communities. The differences in mean nitrifiable nitrogen at the center, edge, and adjacent locations in small, medium, and large communities is shown in Figure 10.

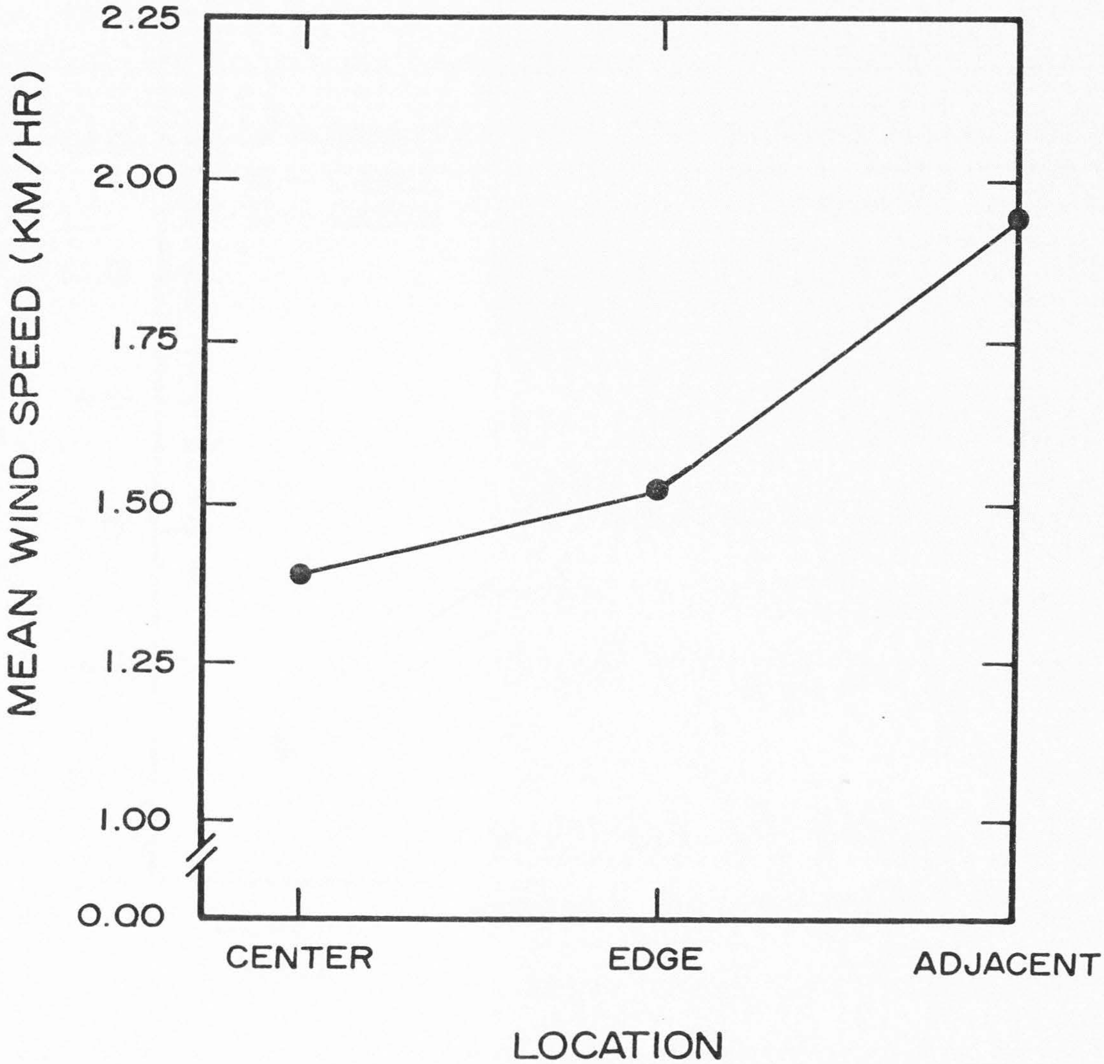


Figure 9. Mean wind speed (kilometers per hour) in the Carex communities at the center, edge, and adjacent locations.

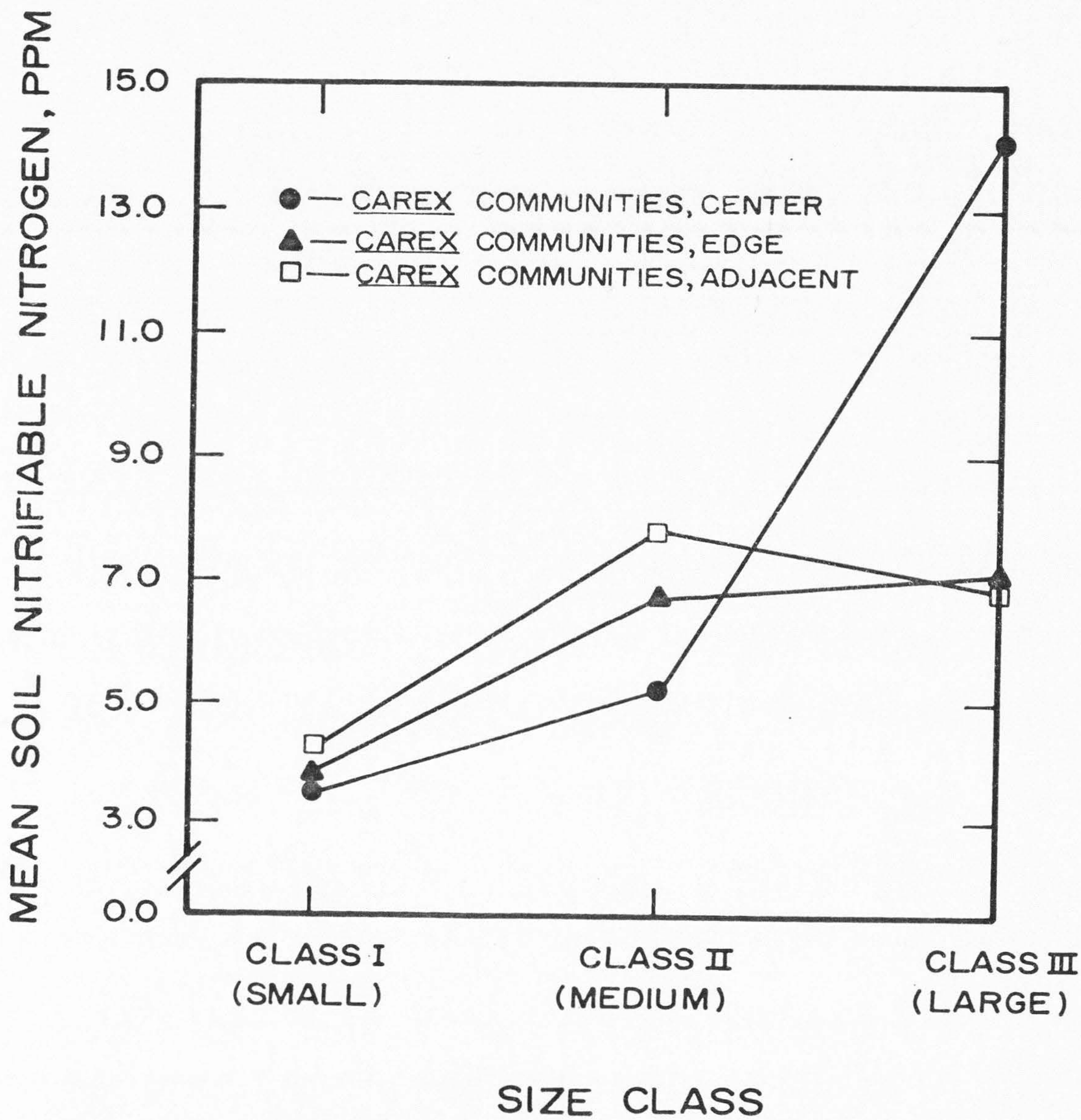


Figure 10. Mean soil nitrifiable nitrogen (ppm) at the center, edge, and adjacent locations in the *Carex* communities for size classes I, II, and III.

The mean extractable potassium was higher in the Carex communities (98.79 ppm) than in the bare areas (88.50 ppm) ($p<2.5$ percent). The largest differences in mean potassium was between small pairs and the large pairs ($p<0.05$ percent) (Figure 11). Within Carex communities, mean extractable potassium was significantly higher ($p<2.5$ percent) in large communities than in either small or medium sized communities (Figure 11). Mean potassium did not vary significantly with center, edge, and adjacent locations within each community size.

The mean pH and mean available phosphorus did not vary significantly with location of sampling within the paired areas.

The higher levels of mean nitrifiable nitrogen and mean extractable potassium in the large Carex communities than in the smaller communities indicated a significant contribution to soil nutrient status with community development. Apparently vegetative and litter cover increased the levels of nitrogen and potassium in the spoils through the metabolism of the vegetation and the breakdown of organic matter by chemical and microbial activity. Crocker and Major (1955) reported that during initial stages of plant succession, the rate of development of the soil nitrogen profile, depended upon the pattern of plant distribution.

Laboratory analyses of nitrifiable nitrogen were not indicative of field responses because they were conducted under optimal moisture and temperature conditions for microbial growth. The tests did indicate the relative potential of the soil samples taken from different locations on the study area. Microbial activity is low in alpine regions due to the low temperatures (Faust and Nimlos 1968).

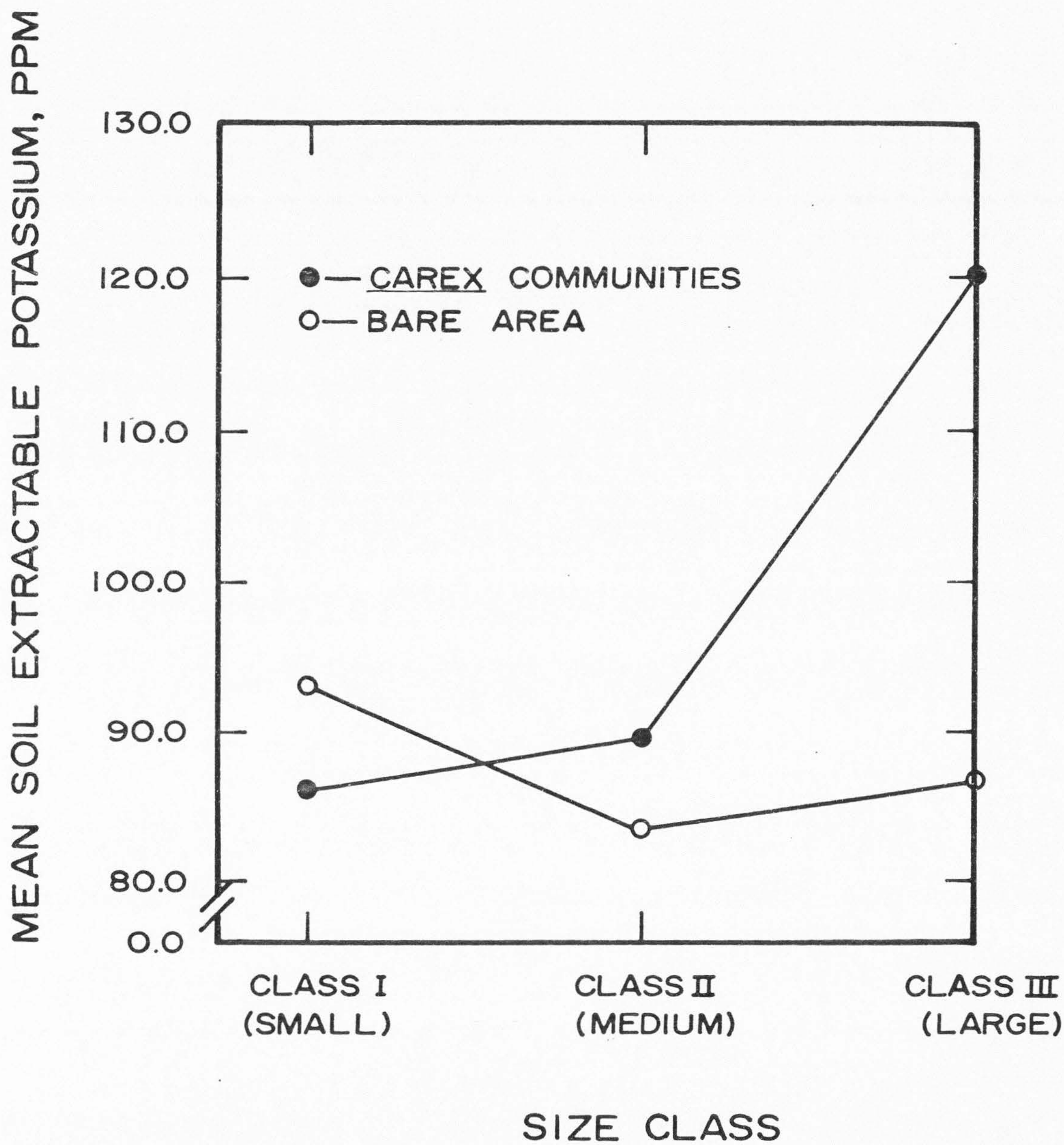


Figure 11. Mean soil extractable potassium (ppm) in the Carex communities and bare areas for size classes I, II, and III.

Nitrogen, phosphorus and potassium availability to plants decreases with pH <5.5. The mean pH for the study area was 4.6. Soil pH has less influence on potassium than on phosphorus availability (Lucas and Davis 1961).

Precipitation, air temperature, relative humidity and solar radiation. Total precipitation for the 1977 field season during the period from June 17 to September 9 was 349 mm. Storm frequency was high, characterized by afternoon thunder storms and by a 20-25 cm snow storm during August 25 and 26. Air temperature at 15 cm varied greatly. Mean daily air temperature was 9.6°C, with a mean daily minima of 3.7°C and a mean daily maxima of 15.7°C. On 12.5 percent of the nights, temperatures $\leq$ 0°C occurred. Mean daily relative humidity was 55.5 percent, with relative humidity 100 percent on 63 percent of the days. Solar radiation fluctuated markedly due to varying amounts of cloud cover. Mean daily solar radiation was 1.40 cal $cm^{-2}min^{-1}$ with peaks < 1.60 cal $cm^{-2}min^{-1}$ occurring several times during the season. The mean weekly air temperature, relative humidity and solar radiation are shown in Table 7.

Knowledge of the effects of the physical characteristics of *Carex* communities on modifying microenvironmental factors in subalpine areas, suggested methods for revegetation of mine spoils, some of which are presently being used at the McLaren Mine (Brown and Johnston 1976, Brown et al. 1976).

Revegetation techniques attempt to match plant adaptability with the environment. When the severity of the environment prohibits plant establishment and growth, as is common on disturbances, ameliorative treatments may be required to alter them. On bare mine

Table 7. Mean weekly air temperature, relative humidity, and solar radiation for the 1977 field season, recorded during the period from June 27 to September 7, 73 days.

Date	Air Temperature (°C) at 15 cm			Relative Humidity (%)	Solar Radiation
	Mean daily minima	Mean daily	Mean daily maxima	Mean daily	($cal\ cm^{-2}\ min^{-1}$) Mean daily maxima
6/27 - 7/3	2.0	8.0	13.9	43.3	1.37
7/4 - 7/10	2.2	6.8	13.1	58.4	1.53
7/11 - 7/18	4.6	11.6	18.6	40.9	1.46
7/19 - 7/24	7.9	14.2	20.6	60.8	1.36
7/25 - 7/31	4.8	11.0	17.1	58.9	1.44
8/1 - 8/7	3.9	10.1	16.3	55.3	1.44
8/8 - 8/14	2.5	9.1	15.6	56.6	1.39
8/15 - 8/21	5.2	12.5	19.7	58.3	1.38
8/22 - 8/28	1.8	5.5	9.1	72.5	1.28
8/29 - 9/4	1.4	6.2	10.9	57.2	1.34
9/5 - 9/7	5.6	12.3	19.1	40.2	1.33

spoils of the McLaren Mine, Brown and Johnston (1976) and Brown et al. (1976) found that such treatments as fertilization, soil organic matter, and surface mulch are essential for plant growth. Apparently there are many similarities between conditions within the Carex communities and the objectives of revegetation techniques.

Surface mulches are equivalent to litter cover in that they act as a heat trap, reducing evaporation of soil water, lower surface temperatures, and lessen the impact of frost. Transplants provide vegetative propagules and act to lower wind speeds, reduce radiation loads at ground level, and lower surface temperatures. The need for higher nitrogen, phosphorus, and potassium are supplied by fertilizers. Liming increases the pH and the availability of plant nutrients.

SUMMARY AND CONCLUSIONS

Seed viability and succession patterns on acid mine spoils were studied at the McLaren Mine located in the Beartooth Mountains. Greenhouse tests were used to study seed viability from soil samples taken at different elevations on the mine. Paired observations were used to study successional patterns in Carex communities and bare areas on the disturbance. Statistical analyses were used to compare the differences between the Carex communities and the bare areas as to seedling survival, species present, percent cover of plants, litter, and bareground, soil temperature and water potential, soil water content, surface soil temperature, radiation, and wind speed, and soil analyses of pH, nitrogen, phosphorus, and potassium. The conclusions of these studies are:

1. There are adequate viable seeds present on the disturbed area to vegetate the spoils. A wide variety of viable seeds of several species were present in the soil samples taken from the mine.

2. The nubmer of seeds and species in soil samples taken from the spoils decrease with increase in elevation on the disturbed area. There was no correlation of number of seeds per sample with distance from undisturbed vegetation at the same elevation.

3. Seedlings were present in both the Carex communities and the bare areas, but seedling survival was significantly greater in the Carex communities ($p<0.1$ percent). Disruption of seedling roots by frost action apparently was the main cause of seedling mortality during the 1977 field season.

4. There were 12 species present in the Carex communities, with Carex paysonis as the dominate species. There was only one species, Erigeron peregrinus, located in the bare areas.

5. The Carex communities had a 84.3 percent crown cover, 17.0 percent basal cover, and 46.1 percent litter cover. The bare areas had no crown cover, 0.06 percent basal cover, and 0.6 percent litter cover.

6. Species diversity, as measured in number of species present, and percent litter cover increased as Carex community size increased.

7. Carex communities modified several microenvironmental factors and thus provided a less harsh environment within their boundaries than found in the bare areas. Within the Carex communities, soil surface temperatures and soil temperatures at 5 cm depth were cooler, wind speed and radiation flux density were reduced at ground level, and nitrogen and potassium levels were higher than the bare areas.

8. Soil water potential and soil water content measurements were not sufficiently low in the Carex communities and the bare areas to cause water stress in plants. Storms were frequent throughout the 1977 field season and total precipitation for the season was high (349 mm).

9. Carex communities did not significantly alter soil pH and soil phosphorus levels to differ from bare areas.

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APPENDIXES

Appendix A.

Analysis of variance for measurement of microenvironmental factor differences between Carex communities and bare areas and differences between small, medium and Carex communities.

Table 8. Analysis of variance for measurement of soil temperature (at 5 cm) differences between Carex communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio
Size	2	24.55075	12.27537	0.231
Error A	3	159.1976	53.06587	
Community	1	251.1260	251.1260	11.111
Size x Community	2	84.66808	42.33404	1.873
Error B	3	67.80663	22.60221	
Location	1	35.19004	35.19004	1.455
Size x Location	2	10.49058	5.245295	0.217
Community x Location	1	17.98537	17.98537	0.744
Size x Community x Location	2	2.08525	1.042625	0.043
Error C	6	145.1363	24.18938	
Total	23	798.2366		

Table 9. Analysis of variance for measurement of soil temperature (at 5 cm) differences between small, medium, and large *Carex* communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	206.4338	103.2169	1.275
Error A	3	242.7845	80.92817	
Location	2	42.57144	21.28572	2.465
Size x Position	4	26.86656	6.716639	0.770
Error B	6	51.81400	8.635667	
Total	17	570.4693		

Table 10. Analysis of variance for measurement of water potential differences between Carex communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio
Size	2	31.75833	15.87917	4.155
Error A	3	11.46638	3.822125	
Community	1	19.21004	19.21004	7.305*
Size x Community	2	31.75833	15.87917	6.038*
Error B	3	7.889375	2.629792	
Location	1	14.25938	14.25938	3.836*
Size x Location	2	3.03100	1.51550	0.408
Community x Location	1	0.759375	0.759375	0.204
Size x Community x Location	2	3.03100	1.51550	0.408
Error C	6	22.30175	3.716958	
Total	23	145.46496		

* Significant at $p < 10\%$.

Table 11. Analysis of variance for measurement of water potential differences between small, medium, and large Carex communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	89.85033	44.92577	8.185
Error A	3	16.46633	5.488778	
Location	2	4.81900	2.409500	0.512
Size x Position	4	6.672667	1.668167	0.354
Error B	6	28.25567	4.709278	
Total	17	146.064		

* Significant at $p < 10\%$.

Table 12. Analysis of variance for measurement of soil water content differences between <u>Carex</u> communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	77.80200	38.9010	0.067
Error A	3	1740.031	580.0103	
Community	1	83.50008	83.50008	2.561
Size x Community	2	170.4347	85.21733	2.614
Error B	3	97.80075	32.60025	
Location	1	7.52083	7.252083	1.60
Size x Location	2	80.42467	40.21233	0.886
Community x Location	1	1.260750	1.26075	0.028
Size x Community x Location	2	79.85400	39.92700	0.880
Error C	6	272.3615	45.39358	
Total	23	2610.7205		

Table 13. Analysis of variance for measurement of soil water content differences between small, medium, and large Carex communities.

Source	Degrees of Freedom	Sum of Square	Mean Square	F Ratio
Size	2	406.7449	203.3724	0.533
Error A	3	1144.625	381.5418	
Location	2	40.47622	20.23811	1.023
Size x Position	4	186.3084	46.57711	2.355
Error B	6	118.6807	19.78001	
Total	17	1896.8352		

Table 14. Analysis of variance for measurement of soil surface temperature differences between Carex communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	123.9772	61.98862	1.9843
Error A	12	374.8830	31.24025	
Community	1	297.0881	297.0881	3.323*
Size x Community	2	60.13583	30.06792	0.3364
Error B	12	1072.699	89.39155	
Location	1	428.4150	428.4150	30.4957**
Size x Location	2	82.32190	41.16045	2.930*
Community x Location	1	312.4817	312.4816	22.2433**
Size x Community x Location	2	162.1962	81.09812	5.773*
Error C	24	337.1612	14.04838	
Total	59	3251.3591		

* Significant at $p < 10\%$.

** Significant at $p < 0.05\%$

Table 15. Analysis of variance for measurement of soil surface temperature differences between small, medium, and large Carex communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	163.7723	81.88616	1.2032
Error A	12	816.6900	68.0575	
Location	2	765.1344	382.5672	14.8149**
Size x Position	4	267.1817	66.79542	2.58664*
Error B	24	619.7572	25.82322	
Total	44	2632.5356		

* Significant at $p < 1\%$.

** Significant at $p < 0.05\%$.

Table 16. Analysis of variance for measurement of radiation flux density differences between Carex communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	30.14017	15.07009	0.556
Error A	12	325.0306	27.08588	
Community	1	764.8749	764.8749	47.747**
Size x Community	2	15.08943	7.544713	0.471
Error B	12	192.3410	16.01925	
Location	1	26.41802	26.41802	11.002**
Size x Location	2	29.37434	14.68717	6.117*
Community x Location	1	33.11620	33.11620	13.792**
Size x Community x Location	2	26.743557	13.37178	5.569*
Error C	24	57.62893	2.401206	1.604
Total	59	1500.6471		

* Significant at $p < 10\%$.

** Significant at $p < 0.05\%$.

Table 17. Analysis of variance for measurement of surface radiation flux density differences between small, medium, and large *Carex* communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	37.04121	18.52061	0.407
Error A	12	545.5413	45.46177	
Location	2	164.4966	82.24828	14.093**
Size x Location	4	84.31542	21.07885	3.612*
Error B	24	140.0662	5.836093	
Total	44	971.46073		

* Significant at $p < 2.5\%$

** Significant at $p < 0.05\%$

Table 18. Analysis of variance for measurement of wind speed differences between *Carex* communities and bare areas.

Source	Degrees of Freedom	Sum of Source	Mean Square	F Ratio
Size	2	0.1083603	0.05418017	0.102
Error A	12	6.361952	0.5301627	
Community	1	118.1396	118.1396	191.473**
Size x Community	2	2.219120	1.109560	1.798
Error B	12	7.404032	0.6270027	
Location	1	0.021600	0.021600	0.198
Size x Location	2	1.527325	0.7636625	6.987*
Community x Location	1	1.206017	1.20617	11.034**
Size x Community x Location	2	0.1893583	0.09467917	0.866
Error C	24	2.62320	0.109300	
Total	59	139.80056		

* Significant at $p < 0.5\%$.

** Significant at $p < 0.05\%$.

Table 19. Analysis of variance for measurement of wind speed differences between small, medium, and large Carex communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	0.185833	0.0929167	0.209
Error A	12	5.32620	0.443850	
Location	2	11.30943	5.654717	28.515*
Size x Location	4	1.034933	0.258733	1.305
Error B	24	4.759300	0.1983042	
Total	44	22.615696		

* Significant at $p < 0.05\%$

Table 20. Analysis of variance for measurement of soil nitrogen differences between Carex communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	215.2588	107.6292	1.710
Error A	12	755.8500	62.9875	
Community	1	8.43750	8.43750	0.843
Size x Community	2	112.5250	56.26250	5.622***
Error B	12	120.1000	10.0083	
Location	1	24.70417	24.7040	3.648*
Size x Location	2	18.80823	9.404167	1.388
Community x Location	1	3.037500	3.03750	0.448
Size x Community x Location	2	106.2750	53.13750	7.846**
Error C	24	162.550	6.7729	
Total	59	1527.546	25.89061	

* Significant at $p < 10\%$.

** Significant at $p < 2.5\%$.

*** Significant at $p < 0.5\%$.

Table 21. Analysis of variance of measurement of soil nitrogen differences between small, medium, and large Carex communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square Square	F Ratio
Size	2	232.4778	116.2389	1.812
Error A	12	769.6667	64.13889	
Location	2	24.71111	12.35556	1.558
Size x Location	4	164.7889	41.19722	5.195*
Error B	24	190.3333	7.930556	
Total	44	1381.978		

* Significant at $p < 0.5\%$.

Table 22. Analysis of variance for measurement of soil pH differences between *Carex* communities and bare areas.

Source	Degrees of Freedom	Sum of Square	Mean Square	F Ratio
Size	2	0.3733	0.188667	5.145*
Error A	12	0.44000	0.086667	
Community	1	0.0001667	0.0001667	0.012
Size x Community	2	0.041333	0.020667	1.494
Error B	12	0.166000	0.013833	
Location	1	0.0041667	0.0041667	0.420
Size x Location	2	0.009333	0.0004667	0.470
Community x Location	1	0.0601667	0.0601667	6.065*
Size x Community x Location	2	0.033333	0.016667	1.680
Error C	23	0.23800	0.00992	
Total	59	1.		

* Significant at $p < 2.5\%$.

Table 23. Analysis of variance for measurement of soil pH differences between small, medium, and large Carex communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	0.1351111	0.0675556	1.109
Error A	12	0.7306667	0.0608889	
Location	2	0.1231111	0.0615556	6.675*
Size x Location	4	0.022222	0.0055556	0.602
Error B	24	0.2213333	0.009222	
Total	44	1.2324441		

* Significant at $p < 0.5\%$.

Table 24. Analysis of variance for measurement of soil phosphorus differences between _Carex_ communities and bare areas.

Source	Degrees of Freedom	Sum of Square	Mean Square	F Ratio
Size	2	8.241333	4.120667	0.134
Error A	12	368.9330	30.74442	
Community	1	0.1126667	0.1126667	0.043
Size x Community	2	8.225333	4.112667	1.571
Error B	12	31.41700	2.618083	
Location	1	0.0326667	0.032667	0.007
Size x Location	2	1.529333	0.764667	0.168
Community X Location	1	0.726000	0.726000	0.160
Size x Community x Location	2	6.156000	3.07800	0.676
Error C	24	109.226	4.5511	
Total	59	534.59933		

Table 25. Analysis of variance for measurement of soil phosphorus differences between small, medium, and large _Carex_ Communities.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	6.41111	3.205556	0.116
Error A	12	303.8133	27.56778	
Location	2	5.21911	2.609556	0.582
Size x Location	4	13.29433	3.323556	0.741
Error B	24	107.6867	4.486944	
Total	44	463.4244	10.53237	

Table 26. Analysis of variance for measurement of soil potassium differences between *Carex* communities and bare areas.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Size	2	3441.351	1720.676	1.335
Error A	12	15463.91	1288.659	
Community	1	1590.217	1590.217	7.542*
Size x Community	2	4177.219	2088.609	9.906**
Error B	12	2530.181	210.8484	
Location	1	20.63894	20.63894	0.056
Size x Location	2	606.9376	303.4688	0.819
Community x Location	1	2.293215	2.293215	0.006
Size x Community x Location	2	533.5547	266.7773	0.720
Error C	24	8888.40	370.35	
Total	59	37254.81		

* Significant at $p < 2.5\%$.

** Significant at $p < 0.5\%$.

Table 28. Mean soil temperature (°C) at 5cm in paired areas-and in Carex communities by size, location, and size x location.

Source			No. Obs./ Mean	Carex Communities	Bare Areas
I. Paired Areas - overall			(120)	11.476	13.522
	A. Size	small	(40)	72.650	13.095
		medium	(40)	10.448	13.735
		large	(40)	11.330	13.735
	B. Location	center	(60)	11.585	14.178
		edge	(60)	11.367	12.865
	C. Size x Location				
	Small	center	(20)	12.595	13.325
		edge	(20)	12.705	12.865
	Medium	center	(20)	10.660	14.605
		edge	(20)	10.235	12.865
	Large	center	(20)	11.500	14.605
		edge	(20)	11.160	12.865
II. Carex Communities					
	A. Size	small	(60)	13.298	
		medium	(60)	10.812	
		large	(60)	11.332	
	B. Location	center	(60)	11.585	
		edge	(60)	11.367	
		adjacent	(60)	12.490	
	C. Size x Location				
	Small	center	(20)	12.595	
		edge	(20)	12.705	
		adjacent	(20)	14.595	
	Medium	center	(20)	10.660	
		edge	(20)	10.235	
		adjacent	(20)	11.590	
	Large	center	(20)	11.500	
		edge	(20)	11.160	
		adjacent	(20)	11.335	

Appendix B.

Mean microenvironmental measurements in paired areas and in Carex communities by size, position and by size and position.

Table 30. Mean soil water content (%) in paired areas and in Carex communities by size, location, and size x location.

Source			No. Obs./Mean	Carex Communities	Bare Areas
I. Paired Areas - overall			(60)	24.372	22.703
A.	Size	small	(20)	27.105	22.170
		medium	(20)	23.110	22.355
		large	(20)	22.900	33.585
B.	Location	center	(30)	24.023	22.560
		edge	(30)	24.720	22.847
C.	Size x Location				
	Small	center	(10)	24.710	21.910
		edge	(10)	29.500	22.430
	Medium	center	(10)	22.880	22.460
		edge	(10)	23.340	22.250
	Large	center	(10)	24.480	23.310
		edge	(10)	21.320	23.860
II. Carex Communities					
A.	Size	small	(30)	26.880	
		medium	(30)	23.027	
		large	(30)	21.920	
B.	Location	center	(30)	24.023	
		edge	(30)	24.720	
		adjacent	(30)	23.083	
C.	Size x Location				
	Small	center	(10)	24.710	
		edge	(10)	29.500	
		adjacent	(10)	26.430	
	Medium	center	(10)	22.880	
		edge	(10)	23.340	
		adjacent	(10)	22.860	
	Large	center	(10)	24.480	
		edge	(10)	21.320	
		adjacent	(10)	19.960	

Table 31. Mean surface soil temperature (°C) in paired areas and in *Carex* communities by size, location, and size x location.

Source			No. Obs./ Mean	*Carex* Communities	Bare Areas
I. Paired Areas - overall			(300)	20.102	21.509
A. Size	small		(100)	19.391	21.340
	medium		(100)	21.172	21.691
	large		(100)	19.748	21.497
B. Location	center		(150)	21.669	21.633
	edge		(150)	18.533	21.386
C. Size x Location					
	Small	center	(50)	19.716	21.692
		edge	(50)	10.066	20.989
	Medium	center	(50)	23.232	21.596
		edge	(50)	10.112	21.786
	Large	center	(50)	22.058	21.610
		edge	(50)	17.428	21.384
II. *Carex* Communities					
A. Size	small		(150)	19.642	
	medium		(150)	21.090	
	large		(150)	20.111	
B. Location	center		(150)	21.669	
	edge		(150)	18.535	
	adjacent		(150)	20.639	
C. Size x Location					
	Small	center	(50)	19.716	
		edge	(50)	10.066	
		adjacent	(50)	20.144	
	Medium	center	(50)	23.232	
		edge	(50)	10.112	
		adjacent	(50)	20.926	
	Large	center	(50)	22.058	
		edge	(50)	17.428	
		adjacent	(50)	20.846	

Table 32. Mean surface radiation flux density (microeinsteins cm^{-2} sec^{-1}) and in Carex communities by size, location, and sizes location.

Source	No. Obs./ Means	Carex Communities	Bare Areas
I. Paired Areas - overall	(300)	0.906	1.793
A. Size small	(100)	0.949	1.726
medium	(100)	0.929	1.756
large	(100)	0.840	1.900
B. Location center	(150)	0.967	1.844
edge	(150)	0.944	1.742
C. Size x Location			
Small center	(50)	0.929	1.782
edge	(50)	0.968	1.670
Medium center	(50)	0.920	1.868
edge	(50)	0.937	1.626
Large center	(50)	0.751	1.863
edge	(50)	0.928	1.930
II. Carex Communities			
A. Size small	(150)	1.034	
medium	(150)	1.025	
large	(150)	0.987	
B. Location center	(150)	0.867	
edge	(150)	0.944	
adjacent	(150)	1.235	
C. Size x Location			
Small center	(50)	0.929	
edge	(50)	0.968	
adjacent	(50)	1.204	
Medium center	(50)	0.920	
edge	(50)	0.937	
adjacent	(50)	1.219	
Large center	(50)	0.751	
edge	(50)	0.928	
adjacent	(50)	1.282	

Table 33. Mean wind speed (km hr^{-1}) in paired areas and in *Carex* communities by size, location, and size x location.

Source			No. Obs./ Mean	*Carex* Communities	Bare Mean
I. Paired Areas - overall			(300)	1.457	2.885
A.	Size	small	(100)	1.526	2.777
		medium	(100)	1.494	2.826
		large	(100)	1.351	3.051
B.	Location	center	(150)	1.394	2.967
		edge	(150)	1.519	2.803
C.	Size x Location				
	Small	center	(50)	1.495	2.867
		edge	(50)	1.558	2.687
	Medium	center	(50)	1.480	3.035
		edge	(50)	1.508	2.617
	Large	center	(50)	1.208	2.998
		edge	(50)	1.493	3.105
II. *Carex* Communities					
A.	Size	small	(150)	1.663	
		medium	(150)	1.650	
		large	(150)	1.588	
B.	Location	center	(150)	1.394	
		edge	(150)	1.519	
		adjacent	(150)	1.987	
C.	Size x Location				
	Small	center	(50)	1.495	
		edge	(50)	1.558	
		adjacent	(50)	1.937	
				480	
	Medium	center	(50)	1.508	
		edge	(50)	1.961	
		adjacent	(50)	1.208	
				493	
	Large	center	(50)	1.063	
		edge	(50)	1.	
		adjacent	(50)	1.	

Table 34. Mean nitrogen (ppm) in paired areas and in *Carex* communities by size, location, and size x location.

Source			No. Obs./ Mean	*Carex* Communities	Bare Means
I. Paired Areas - overall			(30)	6.733	5.983
A. Size	small		(10)	3.550	4.050
	medium		(10)	6.050	7.850
	large		(10)	10.600	6.050
B. Location	center		(15)	7.600	6.400
	edge		(15)	5.867	5.567
C. Size x Location					
	Small	center	(5)	3.500	4.800
		edge	(5)	3.600	3.300
	Medium	center	(5)	5.200	9.000
		edge	(5)	6.900	6.700
	Large	center	(5)	14.100	5.400
		edge	(5)	7.100	6.700
II. *Carex* Communities					
A. Size	small		(15)	3.767	
	medium		(15)	6.633	
	large		(15)	9.333	
B. Location	center		(15)	7.600	
	edge		(15)	5.867	
	adjacent		(15)	6.267	
C. Size x Location					
	Small	center	(5)	3.500	
		edge	(5)	3.600	
		adjacent	(5)	4.200	
	Medium	center	(5)	5.200	
		edge	(5)	6.900	
		adjacent	(5)	7.800	
	Large	center	(5)	14.100	
		edge	(5)	7.100	
		adjacent	(5)	6.800	

Table 35. Mean ~~p4~~ pH in paired areas and in *Carex* communities by size, location, and size x location.

Source			No. Obs./ Mean	*Carex* Communities	Bare Areas
I. Paired Area - overall			(30)	4.62	4.62
A. Size	small		(10)	4.69	4.76
	medium		(10)	4.55	4.52
	large		(10)	4.62	4.57
B. Location	center		(15)	4.56	4.64
	edge		(15)	4.66	4.59
C. Size x Location					
	Small	center	(5)	4.68	4.78
		edge	(5)	4.70	4.74
	Medium	center	(5)	4.48	4.58
		edge	(5)	4.62	4.46
	Large	center	(5)	4.58	4.56
		edge	(5)	4.66	4.58
II. *Carex* Communities					
A. Size	small		(15)	4.72	
	medium		(15)	4.59	
	large		(15)	4.64	
B. Location	center		(15)	4.58	
	edge		(15)	4.66	
	adjacent		(15)	4.71	
C. Size x Location					
	Small	center	(5)	4.68	
		edge	(5)	4.70	
		adjacent	(5)	4.78	
	Medium	center	(5)	4.48	
		edge	(5)	4.62	
		adjacent	(5)	4.66	
	Large	center	(5)	4.58	
		edge	(5)	4.66	
		adjacent	(5)	4.68	

Table 36. Mean phosphorus (ppm) in paired areas and in Carex communities by size, location, and size x location.

Source	No. Obs./ Mean	Carex Communities	Bare Areas
I. Paired Areas - overall	(30)	8.45	8.36
A. Size small	(10)	9.22	8.58
medium	(10)	8.30	7.72
large	(10)	7.82	8.78
B. Location center	(15)	8.53	8.23
edge	(15)	8.36	8.49
C. Size x Location			
Small center	(5)	8.82	8.50
edge	(5)	9.62	8.66
Medium center	(5)	8.26	7.82
edge	(5)	8.34	7.62
Large center	(5)	8.52	8.36
edge	(5)	7.12	9.20
II. Carex Communities			
A. Size small	(15)	8.60	
medium	(15)	8.33	
large	(15)	7.70	
B. Location center	(15)	8.55	
edge	(15)	8.36	
adjacent	(15)	7.74	
C. Size x Location			
Small center	(5)	8.82	
edge	(5)	9.62	
adjacent	(5)	7.36	
Medium center	(5)	8.26	
edge	(5)	8.34	
adjacent	(5)	8.40	
Large center	(5)	8.52	
edge	(5)	7.12	
adjacent	(5)	7.46	

Table 37. Mean potassium (ppm) in paired areas and in *Carex* communities by size, location, and size x location.

Source			No. Obs./ Mean	*Carex* Communities	Bare Means
I. Paired Areas - overall			(30)	98.79	88.50
A.	Size	small	(10)	86.02	93.84
		medium	(10)	89.93	83.67
		large	(10)	120.43	87.98
B.	Location	center	(15)	98.01	88.10
		edge	(15)	99.57	88.89
C.	Size x Location				
	Small	center	(5)	86.80	96.19
		edge	(5)	85.24	91.89
	Medium	center	(5)	81.33	82.11
		edge	(5)	98.53	85.24
	Large	center	(5)	125.90	86.02
		edge	(5)	144.95	89.93
II. *Carex* Communities					
A.	Size	small	(15)	90.71	
		medium	(15)	90.45	
		large	(15)	117.04	
B.	Location	center	(15)	98.01	
		edge	(15)	99.57	
		adjacent	(15)	100.62	
C.	Size x Location				
	Small	center	(5)	86.80	
		edge	(5)	85.24	
		adjacent	(5)	100.10	
	Medium	center	(5)	81.33	
		edge	(5)	98.53	
		adjacent	(5)	91.49	
	Large	center	(5)	125.90	
		edge	(5)	114.95	
		adjacent	(5)	110.26	